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ADDRESS AT THE ANNUAL CONVENTION AT HYGEIA HOTEL, FORTRESS MONROE, VA., JUNE 8TH, 1892.

By MENDES COHEN, President, Am. Soc. C. E.

A provision of the Constitution of the Society requires that the President shall deliver an address at the Annual Convention, and, in compliance therewith, I have the honor to appear before you this evening. As I have not been of late years actively engaged in the practice of our profession, and am, for that reason, unable to give from personal experience notes of recent works and improvements marking the strides of current progress in the science of engineering, it has been suggested to me that you would be interested in a historical narration of some of the events and problems of a much earlier period, and the manner of meeting them in the construction, development and operation of the Baltimore and Ohio Railroad. It must not be understood from my assuming to act upon this suggestion, that I was one of those upon whom these early duties and responsibilities devolved. I was not born until some years after the 4th of July,

1828, when the venerable Charles Carroll, of Carrollton, then the only survivor of those who signed, in 1776, the charter of our liberties, turned the first sod and laid the first stone of the Baltimore and Ohio Railroad. But many of the original actors and participants in these events were still upon the stage when, as a youth, I entered the locomotive shops of the late Ross Winans, with a view to preparation for the profession of a civil engineer.

Mr. Winans, a native of New Jersey, was himself a most prolific inventor, and had produced, previous to 1829, an improved journal and box which he thought suited to railroad use, and which he went to England to test on the Liverpool and Manchester Railroad, then under construction. He was there present when the celebrated trial of locomotives took place in 1829, and the opportunity thus afforded him for a study of the locomotive was not lost, and was subsequently of much value both to himself and the railroad company. His journal and box were adopted on the Baltimore and Ohio Railroad, and he, taking up his permanent residence in Baltimore, had been continuously thereafter engaged in designing and constructing cars and locomotives adapted to use on the railroad.

In and about the establishment of Mr. Winans and the railroad works adjoining were many of the men who had been employed at the very commencement of the undertaking, the actual participants in which have now nearly all passed away. These men I used to meet constantly, and entering myself into the service of the railroad company a few years later, while many of the original features of the work were still in existence, I had opportunities of acquiring facts and of observing details not so readily gathered or noted to-day. Being in this sense only a survivor of that early period, I venture to bespeak your interest and attention to some of the more prominent details of the work in which there was much originality. Many of these facts are known to some of you, many of them are here gathered from the original reports and other records of the time, some from a history of the railroad prepared in 1853 by the late William Prescott Smith, and others from the personal reminiscences of survivors, but I am not aware that they have ever before been brought together.

In 1825 Baltimore was a city of about seventy thousand inhabitants. Its people were enterprising, and had developed with the country beyond the Alleghanies a large trade, transported in wagons over good

turnpike roads, while the foreign commerce of the port conducted in its home-built, fast sailing vessels, known everywhere as "Baltimore Clippers," extended to all parts of the world. Its geographical position, giving it a saving of from 100 to 200 miles in distance to the Ohio River at Wheeling over that from Philadelphia or New York to the same river at Pittsburgh, was sufficient, when land transportation was effected only by horse and wagon, to give it an enormous advantage. Philadelphia and New York were making strenuous efforts to retain their trade, and to this end were pressing forward their respective lines of canal, the future possibilities of which, aided by steam navigation then rapidly developing, no imagination would limit.

Baltimore had not failed to realize early that action was necessary. It was believed that the valleys of the Potomac and Youghiogheny rivers would afford a route for a canal quite as advantageous as any to the north of it. Washington, himself, had taken much interest in such a project, and had presided in December, 1784, at a meeting in Alexandria, at which the Potomac Company was formed for improving the navigation of that river. In 1824, a charter for the Chesapeake and Ohio canal was granted by Virginia and Maryland. Into this corporation was merged the Potomac Company, which had thus far only accomplished the opening of a partial slack water navigation. Preliminary surveys for the canal had been made and some definitive location effected, when the hopes of Baltimore as to its commercial success were completely upset by the report of General Bernard, of the Board of Engineers on Internal Improvements, who in 1826 showed not only the very great cost of the work, but that the scarcity of water on the Alleghanies at the high elevation over which the canal must pass, made its successful accomplishment very problematical; besides, its proposed eastern terminus was Georgetown on the Potomac, and to reach Baltimore from that point would involve an additional cross-cut canal some 50 miles in length.

The opening of the Erie Canal in 1825 aroused the merchants of Baltimore to a full sense of impending decadence, and discussions of the subject were constant between the more thoughtful of their number. If the projected canal was out of the question, what were they to do? Competition by the best of turnpike roads was hopeless! At this time attention was being directed in England to the possibilities

of railroads for general transportation purposes. Numerous short lines were already in existence there, and a very few had been laid even in this country, but so far they were designed chiefly, if not altogether, for the purpose of moving mineral products from mines or quarries to a convenient point where water transportation would be available, and were, in fact, what we would term to-day mere tramways, and only operated reliably by horses. Might not this new system be made available on a larger and much more extended scale for connecting Baltimore with the western waters? So thought Philip E. Thomas and George Brown, two of these Baltimore merchants. Having facilities for obtaining information from England in regard to what had been done there, these gentlemen took pains to procure all that was available from that source, and with it in hand they invited a few of Baltimore's most influential citizens to meet them for the purpose, as their call stated, "To take into consideration the best means of restoring to the City of Baltimore that portion of the western trade which has been lately diverted from it by the introduction of steam navigation and by other causes."

This meeting was held at the residence of Mr. Brown on the 12th of February, 1827. It was well attended. After hearing read and discussing the various documents and statements illustrating the efficiency of railroads for the conveying of articles of heavy carriage at a small expense, and the superior advantage of this mode of transportation over turnpike roads or canals, a committee was appointed to consider the subject, and was directed to report to an adjourned meeting one week later. At this adjourned meeting it was determined to apply to the Legislature, then in session, for a charter for the Baltimore and Ohio Railroad. This was obtained in the following month in such a comprehensive form that it remains to this day a monument to the forethought of those who prepared it. This was the commencement of the Baltimore and Ohio Railroad Company, the first railroad enterprise undertaken for general commercial purposes certainly in the United States, and far exceeding in magnitude anything then being promoted in England.

Organizing at once under this charter, Phillip E. Thomas became the first president of the company, and, with an efficient Board of Directors, lost no time in prosecuting the work. Application was made to the United States Government for a detail of officers to conduct

reconnaissances and surveys, to be at once undertaken, while the company would take time for the careful selection of a suitable chief engineer. In response to this application there were detailed to the railroad service, S. H. Long, Brevet Lieut.-Col. U. S. Topographical Engineers; William Gibbs McNeill, Captain U. S. Topographical Engineers; Dr. William Howard, U. S. Assistant Engineer, assisted by Mr. F. Harrison, Jr., U. S. Assistant Engineer; Lieutenants Joshua Barny, U. S. Artillery; Isaac Trimble, U. S. Artillery; John L. Dellahunty, U. S. A.; Walter Gwynn, U. S. A.; William Cook, U. S. A.; Richard E. Hazzard, U. S. A.; George W. Whistler, U. S. A.; Fessenden, U. S. A.; Thompson, U. S. A., and Mr. Guion.

The duty assigned to these officers was performed with so much assiduity that they were enabled to present on the 5th of April, 1828, a report which covered a general examination of the whole intervening region between the Patapsco and Ohio rivers, and with so intelligent a discussion of many of the alternative lines that it is a matter of no little wonder how so much could be accomplished in so short a time, through so rough a wilderness as the Alleghanies must have been in that day. The study of the route seems to have been based on the theory that the gradient of the road, to be worked probably by horses, possibly by locomotives, must be moderate, not exceeding 30 feet per mile, as nearly uniform as possible, never undulating, that a very liberal amount of lateral curvature was admissible in furtherance of this, and for the avoidance of heavy cuts and fills; and that where summits were to be crossed and great differences of level to be overcome, recourse should be had to inclined planes, to be operated preferably by steam or water power.

The company had, in the meantime, secured the services of Jonathan Knight, Esq., of Pennsylvania, a civil engineer of experience, who had been engaged upon the National Road between Cumberland and Wheeling, and who had served more recently under appointment of the U. S. Government as a commissioner to extend that road from Wheeling through the States of Ohio and Indiana. A few days after the filing of the report of reconnaissance and survey, the engineering department was organized by placing it in charge of a Board of Engineers, consisting of the president of the company, Mr. Philip E. Thomas, Colonel S. H. Long, U. S. Topographical Engineers, and Jonathan Knight. The president had no knowledge of engineering, so there were two

professional men with a layman to vote with one or the other and make a majority whenever a difference of opinion supervened. Captain McNeill was subsequently, on October 6th, 1828, appointed a fourth member of the Board.

On May 5th, 1828, the Board of Engineers made a formal report recommending to the company the adoption of a route by the valley of the Potomac, as affording by far the best passage through the South Mountain, involving too the crossing by inclined planes of but one summit, that of Parr's Ridge, before reaching the Potomac. A few days later, parties were started in the field to make definitive location of the line. It is curious to note that in the midst of their labors in the location of a great line through a difficult country, the Board of Engineers found they had quite as difficult a problem to solve in meeting the views of the citizens of Baltimore as to the city terminus of the line. Every merchant wanted it at his own door, and it was many years before the question was put to rest.

On July 4th, 1828, formal commencement of the work was made by the laying of the first stone, by Charles Carroll, of Carrollton, attended by a great procession and trades' display, badges, music, etc., and on the 14th of the same month the first letting of the work took place. That there was no time being then lost is clear, for, at the annual meeting, less than ninety days later, the President reports that the grading of 1½ miles was complete.

Simultaneously with the location of the line at Baltimore a party had been sent to locate the road through the Narrows of the Potomac, at and beyond the Point of Rocks, where it was feared there might be contest with the Chesapeake and Ohio Canal Company. This was promptly effected and was followed by the acquisition of the coveted ground in fee simple, though to no purpose, as it presently appeared, for in the same annual report of October 1st, 1828, the President announced that the Canal Company laid claim to a pre-emption right to a location along the Potomac River through succession to the rights of the old Potomac Company. Injunction immediately stopped the work of the railroad company along the Potomac, and the litigation thus commenced was prolonged for several years, ending finally in the triumph of the Canal Company.

The same report announced the intention of the President and Board of Directors to send to England a deputation of engineers to

make observations there, and especially to study the application of moving power upon the roads there existing. Mr. Knight, Captain McNeill and Lieutenant Whistler were accordingly sent abroad in November, 1828. They made a very thorough examination of all the railroads then existing in England, and returned to Baltimore May, 1829. The report of their observations, though promised, was deferred, and, if prepared, seems never to have been formally presented and never printed.

At their very first meeting on the 12th of April, 1828, the Board of Engineers appointed Mr. Casper W. Weaver, Superintendent of Construction, "whose duty it should be to aid in arranging contracts for the execution of work upon the railroad and to see that all contracts for the construction of said road be faithfully carried into effect, and also to perform such other duties connected with the service as the Board of Engineers may direct." Mr. Weaver had been engaged in a somewhat similar capacity on the construction of the National Road from Cumberland to Wheeling and its continuation in Ohio, and, although probably not equipped with a scientific education, had acquired considerable experience and practical skill in dealing with contractors and pushing public works. The Board of Engineers, on the contrary, with a most cumbrous organization, was dealing with entirely new problems where precedents and past experience were of little avail. The Superintendent seems to have thought he possessed far more knowledge of the subject than his engineers and would brook no control. He seems to have recognized their general lines of location, but modified and changed them occasionally as he thought fit.

The Board of Engineers adopted in its printed regulations a thorough system in accordance with the military training and habits of a majority of its members, and not differing from the methods observed in the Government work. Mr. Knight, united with his colleagues in the adoption of these regulations, all of which were doubtless right in themselves, but they were not elastic enough for the views of Superintendent Weaver, who did pretty much as he pleased, without the slightest attention to regulations when he chose to ignore them. It is very evident to one who studies the record to-day, that the Superintendent had the ear of the President and was sustained by him and the Board of Directors. They wanted the work driven with energy in order to impress the public with confidence in the success of a new and

untried enterprise, for the company was seeking support and subscriptions to its stock from both the State and the United States Governments.

Mr. Weaver seems to have rushed things, which was what they wanted, and the man who, without drawings or prepared plans, would assume to put contractors to work on dressed stone viaducts of 80, 55 and 20-foot spans, at an estimated cost but little exceeding that which the Board of Engineers had named as the cost of wooden superstructures, adopted by them for economy, was the man for the day. Colonel Long seems to have had much trouble from this cause during the absence of his colleagues in England. On their return in May, 1829, there was an investigation; charges were preferred against the Superintendent, such as changing location without authority, injudicious dealings with contractors, entire disregard of certain specific orders of the Board of Engineers, etc. A hearing was had before a committee of the Board of Directors which acquitted the Superintendent of all charges affecting his integrity and practically sustained him throughout.

The Board of Directors soon thereafter, on the 4th of January, 1830, abolished the Board of Engineers and appointed Jonathan Knight as Chief Engineer. This action gave rise to much acrimonious discussion in the newspapers of the day. A pamphlet of some five hundred pages was published, giving minute details of the work of the Board of Engineers from the first organization of the Board to its final dissolution, and this, in connection with other pamphlets and newspaper articles, give a pretty clear insight as to the actual condition of affairs. A study of it is interesting as showing how the engineers were led, principally by local jealousies, as to the point of entrance into the city, combined with a supposed necessity for avoiding undulations in the grade which had been located as a level for the first six or seven miles, to the adoption of a most expensive line within the first three miles from the city, involving a costly viaduct, and one thorough cut of 310 000 cubic yards. It was thought by this location "a line of road would be secured which, by some extensive embankments and sharp cutting near the city, could be located with but a single summit for a distance of 180 miles, and with but two summits requiring stationary power along the entire distance to the Ohio River."

It enables us further to appreciate how thoroughly novel and un-

tried were the problems involved. We find an elaborate defense of the proposition that the flanges of the wheels should be on the outside of the wheel and rail, an arrangement which the Board of Engineers had adopted, and in accordance with which one and a half miles of track had been actually laid, when shortly after the abolition of the Board of Engineers, the Chief Engineer changed it to that which was then used abroad, and which has since everywhere prevailed. Mr. Knight, in his annual report of October, 1830, explains the reasons for this change of plan and discusses the question very fully; the result being that, while his analysis would seem to justify the conclusion that the flange was better on the outside, and in that position peculiarly well suited to Mr. Winans' patent car, which it was proposed to use, yet as experiments on the Liverpool and Manchester Railroad had shown that this car would work well with the flanges inside, it was desirable that a railroad which must be a general thoroughfare and probably intersected by numerous branches, should be suited to all approved kinds of carriages, of which all, so far, had inside flanges. Hence the conclusion to adopt upon this road the form already in use elsewhere. The same report contains an elaborate discussion and analysis of the size, weight and form of the chilled cast-iron wheel to be used on the road with the proper amount of cone to be given to the thread, resulting in a pattern which was standard for the next twenty years or more. Of cars, a number were constructed at this time with case-hardened or steeled journals and chilled bearings, a system which also continued in use for over twenty years.

Here, I must mention the name of John Elgar, Mr. Knight's mechanical assistant, who was employed in designing and constructing wheels, chairs and turn-outs or switches. The latter were still used in and about the yards and street tracks of New York some twenty-five years later, where they were known as Baltimore switches. When I knew Mr. Elgar forty-five years ago, he was an old man of about seventy years, gentle, and minutely painstaking in all he did. He was then interested in water-rams, which were constructed for him in Winans' shops. I was frequently assigned to his work and learned to know him well. In fact, the first time I ever held a target was for him in running a line of levels for setting one of his rams to supply water to the Baltimore House of Refuge. The level he used was peculiar. He was too poor to buy an ordinary telescope level, and much too

independent to borrow one, so he made his own. Its use did involve the necessity of being reasonably careful about equal sights, but it served his purpose well, and the four silver quarters which he insisted on my accepting for my afternoon's duty as rodman, was the first pay I ever received for engineering work.

The dissolution of the Board of Engineers was soon followed by the retirement from the company's service of all the United States officers heretofore attached to it. They were all men of ability, and each and all subsequently made a record elsewhere; but it is very evident that the President and Board of Directors had effected a most impracticable organization at the outstart, under which it was well nigh impossible to produce good results.

The track was to have been laid throughout on stone sills, but owing to the scarcity of stone until the valley of the Patapsco could be reached, and for the further reason that the embankments constructed without regard to the directions of the engineers, who had ordered them built in compact layers of full width, as you would build an earthen dam, were not sufficiently settled to afford a proper bed for the stone, it was deemed best to lay the first seven and a half miles with wood. Sleepers, or cross-ties of 7 feet to 8 feet in length, and of from 5 inches to 10 inches in thickness were laid transversely on the road at a distance of 4 feet from center to center. Notches were formed in each sleeper at proper distances to receive stringed pieces 6 inches square, and from 12 feet to 40 feet in length. These were held in place by wooden keys. Under each notch of each sleeper a cavity was excavated in the graded bed to receive 1½ cubic feet of broken stone of a size to pass through a 2-inch ring. This cavity was arranged 18 inches lengthwise of the sleepers, and 12 inches lengthwise of the road, and 12 inches deep. Each sleeper was laid so as to rest firmly on these supports of broken stone.

The iron rails 15 feet long by 2¼ inches wide and ⅝ths of an inch thick were laid on the stringers, about three quarters of an inch from the edge. Iron plates having been let into the wood immediately under the joinings of the iron rails, the ends of each two adjoining rails were fastened to the plate by a screw bolt or nut, or by a nail or spike. The rails were laid a quarter of an inch apart with mitred joints, and were nailed to the wood throughout, through holes made in the rail for the purpose. The projecting corner of the stringer was then

adzed off, that the flange of the wheel might not come into contact with the wood. On the unsettled embankment sub-sills were used under the sleepers or cross-ties. For the first seven miles a double track was constructed of this description, and on the next six miles which carried the work to Ellicott's Mills, one track was made with the wooden stringers on stone blocks, about 16 inches square by 12 inches long, bedded in broken stone, instead of on wooden sleepers or cross-ties. The rails were secured to the block by cast-iron knees. The other track consisted of stone sills, about 16 inches wide by 12 inches deep, bedded in broken stone, forming a continuous base for the iron strap rail. The latter was the standard track, and it is recorded in the reports as believed to be the best known, and superior to the iron rail in use in Europe. Its cost was $2 000 per mile for each track more than the wooden stringer, but its supposed permanency recommended it to the company wherever the proper material could be had.

It was not long, however, before experience began to enlighten the officers to a fact which the President announced a little later; that of the several systems of superstructure just described the first intended to be but temporary was decidedly the best, and the last as decidedly the worst of all. The track was finished with a horse path of gravel or broken stone, and was opened for use to Ellicott's Mills on the 21st of May, 1830, being operated by horses. Among the assistant engineers in charge of the track-laying are found the names of J. Dutton Steele and Squire Whipple.

So much extra expense had been involved in the laying of new track with the stone sills, owing to the distance from the quarry and the difficulty of distributing them ahead of the track, together with the evident inexpediency of using them on unsettled embankments, that, as the work proceeded west of Ellicott's Mills, the Chief Engineer suggested whether the extension could not be more advantageously laid with wood, leaving the stone, or other approved methods, to be availed of for renewals. This policy was not adopted, however, until about 40 miles of single track had been laid with the stone.

In his annual report of October 1st, 1830, Mr. Knight speaks with much satisfaction of the readiness with which a speed of 10 miles per hour has been maintained with horses in the working of the 13 miles of road then in use for four or five months. He refers, too, to the recent eminently successful demonstration of the applicability of the loco-

motive to a railway with curvatures of 400 feet radius, as proved by the trial upon the road of an experimental engine built by Peter Cooper, of New York. This engine was rudely constructed, had but a single working cylinder of 3½ inches diameter and was mounted on the ordinary 30-inch car wheels, which were driven from the engine shaft through the medium of gearing. This, *the first trip of the first locomotive built in America,* took place on August 28th, 1830. A most graphic description of the trial trip was prepared many years ago by the late John H. B. Latrobe. No doubt many of you may recall it, and I will not detain you with further reference to it than to say, that the machine was a mere experiment to prove to the skeptic that the sharp curves of 400 feet radius, or even less, could be readily worked by steam applied through the adhesion of the wheel to the rail. Peter Cooper was interested in proving this, for he was the largest owner of shares in the Canton Company of Baltimore, a real-estate corporation that all, who know anything of the New York stock market, have heard about. Peter Cooper believed that his company's lands were only to be made valuable by the successful development of the railroad project, and he was right. The full recognition of their value is, however, only now being realized after an interval of sixty years.

During this and the following year experiments were made to test the resistance of cars with the Winans' anti-friction box and those with hardened steel journals and chilled bearings. With the former the friction on a level straight road was found to be one four-hundredth part of the load and with the latter one two-hundred and fortieth part of the same. Experiments were also made to test the practicability of turning the street corners of the city with the railroad and cars. It was found that a radius of 60 feet could be readily turned by permitting the wheels on the outside of the curve to roll on the edge of the flange, which was guided by the flange running in a groove in the rail, while the inside or shorter rail remained of the usual form and carried the tread of the opposite wheel.

In his annual report of October 1st, 1831, Chief Engineer Knight acknowledges the aid he has received in the arrangement of the machinery from his assistants John Elgar and Ross Winans, the latter of whom was then engaged in planning the machinery and fixtures for the inclined planes, which were never, however, brought into use.

The directors being desirous of procuring their steam machinery, as far as practicable of American workmanship and anxious to direct the mechanical genius of the country to its further improvement, published on the 4th of January, 1831, an advertisement for locomotives. In this advertisement \$4 000 is offered for the most approved engine and \$3 500 for the next best, the engine to burn coke or coal and not to exceed, in running order, the weight of 3½ tons, not inclusive of tender. Three locomotives were offered to the company in response to this advertisement. Of these only one was found to come up to the requirements of the specification. This engine was the "York," built by Davis & Gartner, of York, Penn. It was designed by Phineas Davis, an ingenious watchmaker of that borough, under the stimulus of the company's advertisement, and who, probably for the purpose of building it, associated himself with Gartner, a machinist of the same place. The weight of the engine, limited by the terms of the specification to 3½ tons, was not exceeded. It had a vertical boiler, and was carried on four of the ordinary 30-inch car wheels. The size of its vertical cylinders I find no where recorded. After undergoing some modifications by which the functions of the cylinders were transmitted to the driving wheels and velocity attained through spur gearing, the engine was found capable of conveying 15 tons at 15 miles per hour on a level.

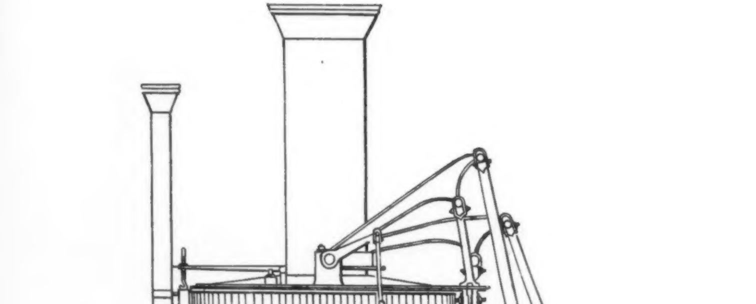
It was put in regular service between Baltimore and Ellicott's Mills, making the distance of 13 miles in an hour with four cars weighing 18 tons gross. About 5 miles of this distance had a grade of 17 feet to the mile. It was found to travel curves of 400 feet radius with facility, even at 15 miles per hour, and on straight parts of the line sometimes attained a velocity, for a short time, of 30 miles per hour. The fuel used was anthracite coal, and answered the purpose well; but the boiler was deficient in size. This engine was at once improved upon by the same builders in their engine "Atlantic," which weighed 6½ tons, of which 4 tons were upon one pair of 36-inch driving-wheels. The boiler was much improved. The upright cylinders of 10 x 20 inches were connected to one pair of driving-wheels by spur gearing, doubling the velocity. The new feature was introduced of cutting off steam at two-thirds of the stroke.

This engine did good work. It was followed from the same shops by the "Indian Chief," soon afterward altered and remodeled as the

"Traveler," and then by the "Arabian," which latter machine became the type of the so-called "Grasshopper engine." This engine weighed $7\frac{1}{2}$ tons. The boiler was vertical, on the model of that of Peter Cooper, with iron tubes. The cylinders, 12 x 22 inches, were connected through spur gearing, not as in the "Atlantic," directly to the axle of the driving-wheel, but to a shaft or axle, about 3 feet in front of the front pair of wheels, parallel therewith and in the same horizontal plane. The ends of this shaft carried cranks which were connected by the usual side rods to cranks on the ends of the driving-wheel shafts, thus transmitting the motion to the driving-wheels. This arrangement, first introduced into the "Traveler," secured the spur gearing from shocks due to the irregularities of the road and disposed finally of a most troublesome cause of breakages. Chief Engineer Knight, in his annual report for 1833, states that the "Atlantic" has run 13 280 miles, burning anthracite coal, of which it had, in that distance, consumed 190 tons without the failure of a single tube.

The building of these engines was now transferred to the company's shops at Mount Clair, under Phineas Davis as contractor, and the work was there conducted by him until his untimely death by an accident to a new engine he was testing, September 27th, 1835. Mr. Davis was succeeded by Gillingham and Winans, who lent their skill to the further perfecting of the machinery and brought these engines to a degree of efficiency which is surprising. So well and so thoroughly was the detail of this engine worked out, and so well adapted was it to hauling heavy loads at slow speeds through curves of the shortest radius, that it has survived to a very recent day. Twenty years ago, when the late Benjamin H. Latrobe prepared for the *Railroad Gazette* a very full and complete description of this engine, it is noted by the editor that four of the engines were still in use. Whether any are in service to-day I am not fully informed, but only a few years ago they were used for yard work at Mount Clair and were very efficient.

While the improvements we have noted in the locomotives, and which we have traced down to 1836, were being effected, other departments of the work were progressing. On the 1st of April, 1832, the line was opened to the Potomac River at the Point of Rocks, a distance of 70 miles from Baltimore, and was regularly worked throughout by horse-power. As already stated, it had been contemplated to effect,



Locomotive Engine "Arabian," used on the Baltimore and Ohio Railroad, designed and constructed for the combustion of Anthracite Coal by Phineas Davis, 1834.

with inclined planes, the crossing of Parr's Ridge, the summit of which was 800 feet above tide and the eastern foot of which was reached at about 40 miles from Baltimore. The placing of the machinery for working of the planes was, however, deferred from year to year, and the traffic carried across the ridge by horse-power, until the development of the engines already described led to their being tested on the heavy grade of the intended planes.

I have already mentioned that, at the very outset, work along the Potomac was stopped by litigation, resulting in favor of the Canal Company; a compromise was sought and finally effected in the spring of 1833. The immediate difficulty was the passage of the several spurs of the Blue Ridge which are cleft by the river with bold and rocky slopes and first encountered by the road in the Catoctin Mountain at the Point of Rocks, and continue at intervals for 12 miles to Harper's Ferry. The compromise arranged need not be considered here. It was onerous enough, but could not be avoided, and under it the work was completed to a point opposite Harper's Ferry by December, 1834.

During these years of obstruction, authority had been obtained to construct a branch road to Washington, and in 1831 Mr. B. H. Latrobe was appointed an assistant and assigned to the reconnaissance. This was followed up without delay by a more definite and careful examination. Mr. Knight takes a most comprehensive view of what he says must become a great national highway. He urges that no grades exceeding 20 feet per mile, nor any curve of less radius than 1 500 feet, or in extreme cases, 1 000 feet, be tolerated if avoidable at any reasonable expense, so that light locomotives may make the run regularly in two hours and indicates the possibility of a "message being made to pass the whole distance from Washington to Baltimore in one hour." The surveys were continued with great minuteness so that, as the President expresses it, "the route finally adopted should leave no better one available to a rival corporation."

In July, 1833, Mr. Knight submits his report and analyses of twelve alternative lines with a degree of elaboration and care that I venture to say has rarely been equaled. The line recommended by him was at once placed under contract, and under Mr. B. H. Latrobe, as the engineer in charge, was completed and opened August 25th, 1835. At its point of divergence from the main stem 7 miles from Baltimore it crosses the Patapsco by a masonry viaduct of eight arches, each of 58-foot chord, some 70 feet in height above the water and of a total length

of 707 feet. This was designed by Mr. Latrobe and stands to-day a monument to his taste and professional skill.

The superstructure of the branch road was intended to be a great improvement on the various forms used thus far on the main stem. It consisted of longitudinal sills 6 inches square, and from 12 to 40 feet in length, laid in trenches, so cut for their reception that the upper surface of the sills will be from 2 to 5 inches below the graded surface of the roadbed. On this were laid crossties 4 feet from center to center, and cut out to receive stringed pieces of yellow pine 6 inches square, on which were laid the first heavy T-rails used on the road. This rail weighed 40 pounds per yard, as proposed by the Chief Engineer and modified in the shape of its face or surface by Mr. Ross Winans.

I must now say something of the progress made in coaches, cars and car wheels. The coaches were at the outstart made about as comfortable as the stage coach of the day, and were built on much the same pattern; but, of course, with cast-iron wheels. The "Ohio," of which I am able to show you a lithograph, was an improvement on those which had preceded it. You will see that it is provided with Mr. Winans' anti-friction boxes. So long as horse-power alone was used, nothing better was required. As soon, however, as the locomotive appeared upon the road, there came with it the necessity for modification in the carriages. The wheels, at first light to save weight, were made heavier to give needed strength with increased speed. Mr. Knight improved the shape of the tread and flange, while John Elgar and Ross Winans developed its chilled features, and Phineas Davis further improved and perfected the whole by altering the disposition of the metal in the tread and angle of the flange, and by introducing within the wheel a wrought-iron ring of $\frac{5}{8}$ or $\frac{3}{4}$-inch round iron, which not only perfected the chill, but increased the strength of the wheel.

So satisfied was Mr. Knight with the result, that he observes at quite an early stage, "the cast-iron wheel has probably attained the utmost perfection of which it is capable." Thousands of these wheels were made at Mr. Winans' shops, not only for use in various parts of this country, but for some of the German and Swiss roads which used them extensively up to 1851. Mr. Knight in his report for 1836 states, that "the chilled wheels have run 30,000 miles and more at the high speed used on the Washington branch without the failure of a single wheel," and he further states that he had every reason to believe that 50,000 miles might be accomplished by them.

PLATE LIII B.
TRANS. AM. SOC. CIV. ENGS.
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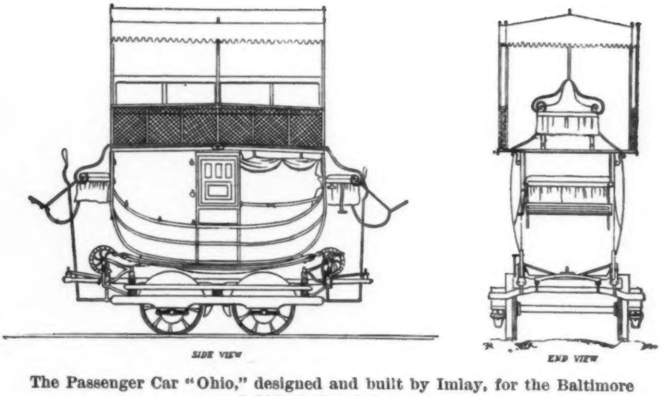
CCHEN ON BALTIMORE AND OHIO RAILROAD.



The Passenger Car "Ohio," designed and built by Imlay, for the Baltimore and Ohio Railroad Company.

The increase of speed due to the use of steam made greater steadiness desirable in the coach than was possible in the four-wheeled car. The long stringers and sills for the track, some of them as long as 40 feet, had been heretofore carried over the finished road on two of the ordinary four-wheel platform cars, coupled by a long pole. On the platform of each of these cars there rested transversely a bolster with a vertical pin, or king-bolt, passing through its middle point and so connected to the platform of the car as to permit the bolster to swivel freely. On these bolsters of the two connected platform cars, and stretching from one to the other, the track timbers referred to were laid. Vertical stakes secured to the ends of the bolsters prevented the timber from rolling off. This contrivance, a very familiar and natural one, and not even then used for the first time, answered its purpose perfectly, and from its steadiness of motion suggested to the active mind of Ross Winans the carrying of passengers on a car constructed on the same principle. His experiments soon followed, and in the annual report of October 1st, 1833, the superintendent of machinery notes that he is building three car bodies to form one coach on eight wheels to carry sixty passengers.

This was the birth of the eight-wheel car which was patented by Mr. Winans and, though the courts, after long litigation, decided adversely to his claim on the ground, I believe, of prior use, as in the case of the timber car and a similar one for transporting large blocks of granite at Quincy, Mass., yet I have always believed that to Ross Winans we are indebted for this great improvement. Very soon thereafter eight-wheel cars were used throughout the line for both passenger and freight traffic, and special cars were provided for baggage, which had theretofore been carried on top of the coaches.

In 1835, James Stimpson, who claimed to have invented a jointed axle, permitting the wheels at each end thereof to revolve independently, applied to President Thomas to have his invention adopted on the road. The question was submitted to Chief Engineer Knight, who reported unfavorably, in a letter to the President, dated May 23d, 1836. In this he discusses at much length the nature of the resistances to which the wheels, axles and rails are exposed. The following passage is worth quoting:

"While upon this particular part of the subject, permit me to advance the belief, that in regard to assigning the relative resistances on different parts of a railroad laid out in straight lines and curves, and in the perfecting of the cast-iron wheel to traverse such a road, not

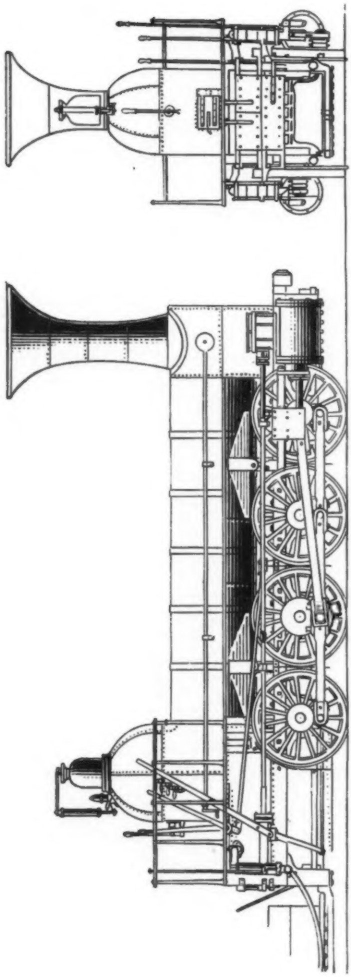
to mention improvements in the locomotive-engine, more has been done at Baltimore upon the railways of this Company than in all the world beside."

I have stated that the road was opened to Harper's Ferry in December, 1834. The portion of the line crossing Parr's Ridge, located for inclined planes with stationary engines at a maximum grade of 270 feet per mile, was still worked by horses, as were also the 12 miles between Point of Rocks and Harper's Ferry. The latter section was so worked on account of the opposition of the Canal Company to the use of locomotives, because they frightened the canal horses. Trials of the new Davis engine, already described, having been made on the planes of Parr's Ridge, and the ability of the engine to overcome even a grade of 270 feet being fully demonstrated, the road across the ridge was re-located to adapt it for locomotive power. This was done with grades of about 80 feet per mile, increasing the distance less than one mile, and was put in operation in June, 1839, when a pecuniary consideration to the Canal Company having meanwhile steadied the nerves of their horses, the whole line, as far as completed, was in operation with locomotives.

The increasing demand for these machines was partly met by replacing the engines at work on the Washington branch by others built by Mr. William Norris, of Philadelphia, having horizontal boilers and one pair of driving wheels of 4 feet diameter, with a truck in usual form, cylinder of 10½ inches diameter and 18 inches stroke, and weighing 9 tons with 5½ tons on the drivers. It was a form of engine much better adapted to the fast passenger service of that line, and was in its day a most efficient machine. These engines used wood fuel and were followed by others on the same general plan, using the same fuel, which was found less costly than the anthracite coal supplied to the Davis engines.

The crossing of the Potomac at Harper's Ferry was effected by a timber bridge, designed by B. H. Latrobe, and built by Wernwag. It was a noted structure in its time, being modeled somewhat upon the plan of a celebrated bridge over the Rhine at Schaafhausen. A peculiarity of the line at this point necessitated a bifurcation of the bridge at its western end, forming two branches of a Y; the one arm connecting by a single span to the south with the Winchester and Potomac Railroad, then just completed, to meet it; the other, by two spans to the west, being the prolongation of the main stem of the railroad.

This arrangement, involving the use of switches midway of the bridge, was necessarily somewhat complicated, but it has continued to



Anthracite Coal-Burning Locomotive "Delaware," built for Philadelphia and Reading Railroad by Ross Winans, Baltimore, 1846.

this day, although the rapidly increasing weight of the locomotives and trains caused the replacing of the timber bridge at a later date, 1852, by an iron truss patented by Wendell Bollman, the details of which were arranged by Mr. J. H. Tegmeyer, and which has been claimed as the first iron truss railroad bridge.

The extension of the line from Harper's Ferry westward to Cumberland, a distance of 96 miles, was now being pressed forward with his characteristic energy by Mr. Latrobe, the engineer of location and construction, and was opened to Cumberland in November, 1842. The engineering features do not call for special comment here, beyond reference to the track superstructure which still adhered to the sub-sill. It consisted of a wooden under-sill and stringed piece with cross-ties and blocks between them, the whole fastened by wooden pins. The iron rail was of the bridge form, weighing 51 pounds to the yard, with cast-iron chairs at the ends and in the middle of the bars, which were held firmly down to the stringed piece by screw bolts at the ends and hook-headed spikes at intermediate distances. The whole resting on a bed of broken stone 1 foot in depth.

A marked stage in the development of the engines for this extension must now be noticed. In 1836 Ross Winans constructed two engines for the road with the Cooper vertical boiler and with the cylinders placed horizontally at the rear end of the frames and connecting by the spur wheel and pinion through the independent shaft to four driving-wheels as in the "Grasshopper" engines. This arrangement enabled the boiler to be depressed and lowered the center of gravity of the whole machine some 12 inches, thereby giving greater stability at high velocity. This plan was further developed in 1842 in seven engines, built for the Western Railroad of Massachusetts, which had eight drivers instead of four. These were powerful machines, but were not a success. They were entirely unsuited to the use of wood; and as anthracite could not be furnished on that line at any reasonable price, the engines were soon laid aside.

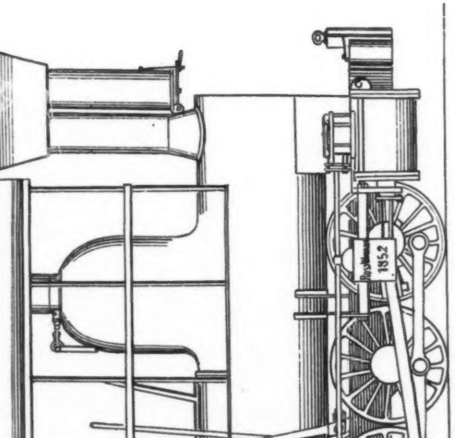
On reaching Cumberland, the Baltimore and Ohio Railroad tapped for the first time the bituminous coal region, and a locomotive was wanted to burn that fuel. Mr. Winans, to meet this demand, designed an engine with horizontal boiler and horizontal cylinders of 16 x 22 inches, connecting with eight driving-wheels 33 inches in diameter, through a spur wheel and pinion as heretofore, and weighing 23½ tons. Twelve of these engines were placed in service between 1844 and 1846,

and were a great advance upon anything which had preceded them. They burned bituminous coal and handled the coal trade in its incipiency. They led the way in the development of the coal-burning engine, the next step in which was the building in 1846, by Mr. Winans, of four engines for the Philadelphia and Reading Railroad with horizontal boilers, horizontal cylinders and eight driving-wheels of 46 inches, diameter, the use of spur gearing being dispensed with.

I mention these Reading engines, of which I am fortunately able to show you a lithograph, for they had no equivalent on the Baltimore and Ohio Railroad, and yet, as the first built with large fire-boxes and horizontal cylinders, connecting directly to the four pairs of driving wheels, they mark an important stage of progress to the next engine, built for the Baltimore and Ohio Railroad, and known as the "Camel." The first of this class of engines was placed on the road in 1848, in response to specifications prepared by Mr. Latrobe and limiting the weight to 22 tons. It had 17-inch cylinders of 22-inch stroke placed horizontally, and eight 43-inch drivers; the fire-box was larger and wider than ever before. In distributing the weight of this engine on its four pairs of driving-wheels, it became necessary to remove the large dome from over the fire-box to a point well forward of the middle of the boiler, where also the throttle valve and engine-man were placed. This humped feature suggested the name "Camel," which was given to the first engine of this form, and the name has since adhered to the type. These engines were developed in the next few years by increase in size of boiler, fire-box and cylinders, which latter were 19 x 22 inches, with a total weight of engine of 28 tons. They were most efficient and enabled the heavy grades of the new road west of the Cumberland to be worked successfully. In fact, the engine was designed for these grades, and there was no other then available for that purpose.

This engine has been further developed and improved upon since, largely in the shops of the Philadelphia and Reading Railroad, to which road many of them were supplied, where its crudities have been removed and its deficiencies supplied by the skill of the several engineers of machinery of that great corporation, notably by the late James Milholland and by Mr. J. E. Wootten; but many of its characteristics and important features can readily be traced—the horizontal cylinders, the large and wide fire-box, the flat connecting and side rods; the latter arranged with fixed bushings incapable of adjustment, a feature much reviled at the time, but now recognized and adoped by the best builders.

PLATE LIII D.
TRANS. AM. SOC. CIV. ENGS.
VOL. XXVI, NO. 533.
COHEN ON BALTIMORE AND OHIO RAILROAD.



The Improved "Camel" Engine, as supplied to the Baltimore and Ohio Railroad, by Ross Winans, Baltimore, Md., 1852.

The progress of the road beyond Cumberland was delayed for five or six years by many and peculiar causes. While the original charters granted by Maryland and Virginia were perpetual, yet there were limitations as to time of completion which were already exceeded, and which now operated to require further legislation; while a limitation in the Pennsylvania charter operated to annul it altogether.

Maryland had a very large amount of money invested in the canal which had not yet reached Cumberland where it now rests, and still cherished the hope of its further extension, so that the railroad location must still be subservient thereto. Virginia endeavored to couple with her grants of extended time, onerous stipulations limiting the terminal point to Wheeling.

The railroad company would have preferred to locate its line to a more southern point on the Ohio, preferably to Parkersburg at the mouth of the Kanawha, and was not insensible to the advantage of a terminus at Pittsburgh, but was evidently averse to Wheeling.

The well-known diplomatic skill of President Louis McLane had full scope in reconciling the difficulties, and with some measure of success, for though the Act of Virginia, of March, 1847, stipulated Wheeling as the terminus, yet the conditions were less onerous than certain earlier acts, under which the company declined to proceed. It contained a section which seems to have been designed to facilitate connection with a branch to Parkersburg. This was so promptly availed of, that the Northwestern Virginia Railroad, now the Parkersburg Branch Railroad, was well under way before the road was opened to Wheeling, and was completed a few years thereafter.

The definitive location of the whole line from Cumberland west was now pushed forward by numerous parties. At the west end three alternative lines of approach to the Ohio presented themselves after avoiding the southwest corner of Pennsylvania, distant from Wheeling some 40 to 50 miles. The first reached the Ohio at the mouth of Fish Creek, the most southern point permitted by the Act of 1847, and then followed the river 25 miles to Wheeling. The next touched the river at the mouth of Grave Creek, 12 miles below Wheeling. The third *via* Wheeling Creek only reached the river at the City of Wheeling. The first, although the longer, had light grades and no heavy work, and was the choice of Mr. Latrobe. The second and third crossed several divides involving much heavy work, each of the two including Board Tree Tunnel of 2 300 feet, with 80-foot grades on either side.

Wheeling, fearing an attempt to deprive her of the benefits of the actual terminus, protested against the adoption of the Fish Creek line as contrary to the spirit of the Act of 1847, and of a subsequent agreement between the city and the company. She called to her aid Jonathan Knight and Charles Ellet, Jr., as engineer experts. Mr. Knight had resigned from the Baltimore and Ohio Railroad, and had been succeeded by Mr. Latrobe, in 1842, about the time of the completion of the road to Cumberland, and now brought all the knowledge and skill acquired in the company's service during his fifteen years of connection with it to bear in opposition to its plans and to the views of its chief engineer, his former assistant. The situation may well have been embarrassing to Mr. Latrobe, whose notions of professional ethics were of a different order.

It will be too long a story to enter here into the details of the controversy. It was skilfully managed on both sides. Reams of paper were filled with the calculations and discussions of the engineers and with the arguments of counsel, among whom were Daniel Webster, Reverdy Johnson and J. H. B. Latrobe. The matter was finally adjusted by arbitration in the autumn of 1850, resulting in the adoption of the Grave Creek line, having caused a further delay of three years.

The questions of location having been settled, the construction of the 200 miles from Cumberland to Wheeling was pressed at all points with energy by able assistants. William H. Small, George Hoffman, Thomas Rowles, James L. Randolph, George McLeod, Charles P. Manning, Benjamin D. Frost, Alfred F. Sears and Albert Fink, the latter a Past President of the Society, are names most of which are familiar to you.

The track from Cumberland westward was laid throughout with 60-pound rails on cross-ties, with a wrought-iron H or lip chair of boiler plate. The latter, though better than anything which had preceded it, was very unreliable. The graded road was ballasted ahead of the track with broken stone, sand or gravel, as might be obtainable. The track was not yet perfect, but a great step in advance was made, when there was no longer a sub-sill to churn away in the mud beneath a real or pretended ballast.

Mr. Latrobe's adoption of the 116-foot grades in crossing the mountains was deemed bold and hazardous, but he had been trained in a school which was self-reliant. He made his calculations of what he required and what he felt sure could be accomplished, and found in Ross

Winans the man who recognized the occasion, and undertook the task of designing an engine that should perform the work. Well do I remember accompanying Mr. Winans on his first test of the new engine on the grade for which it was designed. The occasion was the opening of the new road in July, 1851, to Piedmont station, 28 miles west of Cumberland. Here begins the 116-foot grade which continues for 17 miles to the top of the Alleghany Mountains. The track-laying force was busily engaged some 3 or 4 miles beyond, and this short distance was all that was available to see what the engine could do. As a test of its full power it did not amount to much, but there were attached to the engine, in addition to the passenger cars of the excursionists, a number of car-loads of iron rails, all that were available, and with these the engine started at the foot of the grade and made its run at the rate of 10 or 12 miles per hour with a large surplus of steam, which was cut off at half stroke. On arriving at the end of the track with steam blowing off, there was much congratulation. It was realized that the question of ability to work this grade, of which great doubt had been expressed, was clearly demonstrated with a large reserve of power in the engine, and from that time forward no more was said of impossibilities.

In the following winter and spring the track was carried to and across the slopes of Cheat River. Here, the deep ravines of Tray Run and Buck Eye Hollow were crossed on grades of about 105 feet to the mile at an elevation of some 160 feet above the bed of the ravine by trestle work, soon replaced by permanent structures, the detail of which was executed by our Past President, Albert Fink, then office assistant of Mr. Latrobe.

The next great feature was Kingwood Tunnel of 4,100 feet in length. This work not being ready in time to pass the track-layers through without much delay, Mr. Latrobe determined to grade a track over the tunnel and, passing the iron over it, to continue the work of track-laying beyond. The maximum grade involved in this was 10 feet per hundred, which, though intended for horse-power, was worked by the camel engine, which pushed over it one car of rails without any serious difficulty. At a later period, after the opening of the road, when the arching of the tunnel was in progress, this temporary line was revised with a maximum grade of 5 per cent., and the whole traffic of the road was carried over it for some months. The crossing of this tunnel effected, the progress of the road lay on easier lines for some 80 miles. The Monongahela River was crossed by a bridge of three spans of 200

feet each. The masonry of the piers and abutments of this bridge were entrusted to our late member, Mr. James L. Randolph, who was the division engineer, the superstructure being designed by Mr. Fink.

At Board Tree Tunnel, about 164 miles west of Cumberland, was encountered another temporary delay by reason of the failure or inefficiency of the contractors. Here, Mr. Latrobe again determined to avail of a temporary crossing over the top of the hill. This time the maximum gradient was 6 per cent. The crossing was effected by a series of zigzags, or switchbacks, two on one side of the hill and five on the other. The topography was such that there were two curves on the line of 180 degrees and more of continuous curvature in one direction; the limiting radius was 300 feet. Mr. Latrobe has himself so well described this crossing that I will not repeat it here at length. This temporary road was most successfully worked for some five or six months. Beyond this point for 36 miles to its terminus at Wheeling there are no features of special interest which I now recall. The last rail, completing the track to that point, was laid on the eve of Christmas, 1852, and early in the next month, January, 1853, the formal opening of the road to Wheeling took place.

And now, ere closing an address which has, I fear, already taxed your patience too severely, I will say a word or two of the man who brought this great work to a conclusion. Mr. Latrobe was identified with the Baltimore and Ohio Railroad almost from the very beginning. He had been intended for the law, but after completing his course of study, and being admitted to the Maryland bar, concluded that railway engineering was more to his taste. He entered the service as an assistant to Mr. Knight, and I am quite satisfied that Mr. Knight in all his career never had a more faithful one. None could have been more loyal than he, and when he was no longer an assistant, but himself the chief, his modesty was as marked as before.

While his was the mind which planned and directed all, one might have supposed that the ideas emanated from the assistants, so ready was he to give them credit for their well-executed details. He took pride in the work with which he had been so long identified. He never could have accepted a retainer to oppose its interests whether he was on its pay-roll or not. He left behind him in that portion of the Baltimore and Ohio Railroad which he built, a monument to his professional skill; and in the hearts of his assistants, a loving remembrance not soon to be effaced.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

534.

(Vol. XXVI.—June, 1892.)

SOME NOTES ON THE HOLLAND DIKES.

By WILLIAM STARLING, M. Am. Soc. C. E.

WITH DISCUSSION.

In 1889 the author spent a few days in Holland, and was much impressed by the engineering marvels that he saw. The time was too short and his acquaintance with the country too superficial to make his visit of any profit. He determined, however, to avail himself of the first opportunity for another visit. With this view, after acquiring a little knowledge of the Dutch language, he had some correspondence with acquaintances in Holland, and read a few books that were recommended to him. That which he most desired to study was the dike system. Information was sought especially on the following points:

Sinking and permeable foundations; bad material; prevention of leakage under the dike; dimensions compatible with safety; use of cul-

verts through dikes; protection against storms; causes of breaks; specifications of work; experience with outlets; methods of administration.

A second visit was paid during the summer of 1891. All these subjects were examined to some extent, and more or less information will be found about them in the following pages. The author found the Dutch engineers both intelligent and courteous. He is under particular obligations to Mr. W. F. Leemans, The Hague, Chief Engineer in charge of the Great Rivers; C. F. M. H. Schnebbelie, Bois-le-Duc, Chief Engineer in charge of the New Maas Mouth; Mr. Wisboom, his assistant; Mr. P. H. Kemper, Utrecht, Engineer of the Merwede Canal; Mr. Koole, Resident Engineer of the Westkapelle Dike; Mr. H. E. Bruyn, of the Waterstaat office, at The Hague, and Mr. J. J. L. Bourdrez, of Middelburg, Zeeland, student of Engineering at the Polytechnic College at Delft. All these gentlemen took particular pains to supply him with information, at the cost of some trouble to themselves.

The author visited some of the most remarkable seaworks, which filled him with admiration, but also with despair, as there seemed hardly a possibility of ever being able to imitate them. What interested him particularly were the river dikes, from their close analogy to those of our own country, and it was those, accordingly, that received most of his attention. The Dutch have had the same problems to solve as we, and a study of their methods, adopted after a long experience, ought to be of some profit to us.

The country which we call Holland is denominated by its inhabitants the Netherlands or the Low Countries—the name Holland being restricted properly to the two provinces of North and South Holland. While, on the whole, a flat region, it is not uniformly so. It consists of two separate divisions, of different geological periods, and, of course, diverse in their types. One is strictly alluvial, that is, it was formed while man was on the earth; the other is pre-alluvial, though still belonging to the Quaternary epoch. Briefly, the two divisions may be called uplands and lowlands. The uplands comprise about 41 per cent. of the whole surface of the Netherlands.

The lowlands are not themselves of uniform constitution. They were formed in different ways, are composed of different ingredients, and their history, up to the present time, is altogether dissimilar. Part was formed by deposit from the sea, part from the great fresh-water rivers, and

part from the decay of forests and swamp-growths. The consequence is that the lowlands are composed of strata of clay, sand and peat, the proportions and relative situation of each varying according to locality. Sand and clay are found everywhere, sometimes the one and sometimes the other being the predominant constituent. Peat is often absent altogether, generally appearing at the surface, and sometimes below the surface, at variable distances.

Peat is a rotten, spongy and very compressible soil, which retains and transmits water, and in its natural state is not suitable for cultivation. An artificial sod may be created on the top of it by continued labor, planting, pasturing and manuring, and some very good lands have been formed in this way. In the greater number of cases, however, the peat has been cut away altogether, to the depth of perhaps 6 feet or more, until the solid clay was reached. This generally underlies the peat, forming a stratum of variable thickness. It is very rich and not very stiff, and when treated in the thorough manner which the Dutch farmers practice, it makes a soil of incomparable fertility.

The alluvial land, being produced by deposit from existing rivers and existing seas, the level of which, relatively to the land, has not materially changed, cannot be built up by such deposit to the highest mark of these waters, and must, hence, be liable to overflow in time of flood or storm. Still more must this be the case when the surface strata have been removed to a considerable depth. In order, therefore, that cultivation may be continuous and safe, and that improvements may be fearlessly undertaken and habitations constructed, the land must be protected from inundation. It is well known that this has been effected in Holland by its famous system of dikes.

Dikes, in one form or another, have existed in Holland from a very early time, but the beginnings of the present system are said to date back to about the thirteenth and fourteenth centuries. In the fifteenth century (1421) a terrible storm carried away the sea-dikes for a great distance, destroyed seventy-two towns and villages, inundated 200 000 acres of land, and is said to have cost the lives of 100 000 people. It gave an entirely new conformation to the Lower Rhine and Maas, converting an inhabited district into a great swamp, which has only lately been partially reclaimed. The "Saint Elizabeth's Flood," as it is called from the day of its occurrence (the 18th of November), is thus an important date in the hydrographic history of Holland.

In taking measures for defense against the external waters, it is clear that the most dangerous and pressing enemy is the sea. A great part of the Netherlands is directly exposed to its attacks. North Holland is simply a narrow peninsula, with the sea on both sides. Friesland, Groningen, Gelderland and Utrecht, border on the Zuider Zee. South Holland and Zeeland abut directly on the North Sea. Much of the country is below low tide, nearly all below mean flood. Storms would cause the waves to sweep over the whole land, and the damage that they would do is best shown by the frightful ravages which they have committed in the past. The first and all-essential provision is then to be made against the sea.

Holland is intersected by five large rivers—three branches of the Rhine, the Maas and the Schelde. Of these, the last is hardly a Dutch river at all, as it barely enters the territory of the Netherlands with its estuaries. The others have almost all of their alluvial part in that kingdom. It is impracticable to shut off these rivers from the sea. They are too large. It would be practicable to dam them, but so great is the volume of water which they discharge that it would be well-nigh impossible to keep them drained. Sluices could hardly be built large enough to carry off their waters into the ocean at low tide, and even if this were possible, they would have to be drained by pumping at high tide. Now, the greatest draining machines in Holland have a capacity of about 100 000 cubic meters per hour. The high-water discharge of the smallest of the great rivers, the Maas, is more than eighty times that much. In time of storm, the sea sometimes remains at an extreme height for several days, and the drainage from the river valleys would accumulate in that time to an amount which would be almost as formidable as the sea itself. Therefore, the mouths of the rivers must be left open. But if the mouths are left open, the floods of the ocean will rise in them and overwhelm the lowlands just the same as if they were directly on the sea-coast. Not only so, but the rivers themselves are subject to formidable freshets, rising nearly as high as the floods of the sea. On all these accounts the rivers must be diked, or they will overflow the land.

Owing to the flat slope of the Rhine flood-plain and the close proximity to tide-water, the rivers show a strong tendency toward the delta formation—a tendency to split and wander. Therefore, especially in the lower part of their course, they inter-osculate and are united with

one another by a network of small watercourses. The Lek and the Waal are united by the Noord and the Botlek. The Waal and the Maas are so close together at Fort St. Andries that they have been allowed to merge together in time of flood, and they unite at Woudrichem. By these larger and smaller streams the fluvial part of the Netherlands is divided into a number of islands, each of which has to be completely enclosed by a ring dike. Of these islands some are large and some small. The portion of North Holland lying north of the Y—now the North Sea Canal—is an island. So is the still greater territory composed of portions of North Holland, South Holland, Utrecht and Gelderland, bounded on the north by the Y and the Zuider Zee, on the east by the Yssel, on the south by the Lek and its continuations, and on the west by the German Ocean. A very important island is included between the Lek and the Waal, from their point of separation, and bounded on the west by the Noord, and comprehending the districts called the Over Betuwe, the Neder Betuwe, the Land van Buren, the Land van Culemborg, the Tielerwaard, the Vijfheerenlanden and the Alblasserwaard (see Plate LIV). Being completely inclosed by dikes, these tracts can have no natural drainage. They must either discharge their rain water through sluices into the rivers or the sea, if the latter be low, or be pumped out if the external water be higher than the internal. In point of fact, both these systems have to be resorted to. As the several portions of each inclosed island are of different elevations, some being one foot below mean flood and some fifteen or twenty, the lowest tracts are usually themselves diked in. Moreover, as precautions against possible breaches in the river or sea dikes, there are occasional interior lines of embankment, dividing some of the islands into subordinate districts, and serving, like the water-tight compartments of a ship, to limit the extent of the injury.

Dikes may therefore with propriety be classified as sea dikes, river dikes and internal dikes.

First.—The sea dikes are distinguished by their great strength. As they have to stand the shock of very heavy waves, they must be built with a very long slope—as this has been found one of the most effectual safeguards against damage by breakers. A "sea-beach slope" of 40 or 50 to 1 is of itself usually a sufficient protection against further cutting. Of course, it is not practicable to give so flat a slope as this at all places, or perhaps at any. The front of the dike must then be protected by

artificial means, usually by stone, giving, however, to the dike as flat a slope as possible, consistently with economy—else the stone revetment would have to be too heavy, and would be too precarious. The result of endeavoring to reconcile these two independent principles has been the evolution of a cross-section for the sea dikes which combines some features of each. Of course, mere hydrostatic considerations are entirely lost sight of—the necessity of providing for wave wash making it obligatory to adopt dimensions several times greater than the most liberal allowance for mere pressure would prescribe. Furthermore, as the sea is raised by storms sometimes to a very great height, there must be an ample margin in this respect, the dikes, for complete safety, being 18 or 20 feet higher than mean flood. These extraordinary dimensions are not of universal application. On the Zuider Zee, especially on the western shores, the exposure to storm and tide is not nearly so great as on the North Sea, and the dikes are reduced in size accordingly, though the smallest of them are far larger than would be required to stand the mere head of water to which they are subjected.

Mr. Caland, a well-known Dutch engineer, divides the sea dikes into three classes, as follows : Dikes of the first class, situated immediately on the North Sea, in unfavorable locations, with little or no foreshore, with steep banks, and with a direction perpendicular to the prevailing (westerly) winds. Such embankments have a crown of at least 4 meters, and a front slope of at least 10 to 1, a little convex, with the lower portion somewhat steeper, about 6 to 1, protected by a heavy stone pitching. Dikes of the second class, lying further inland (the shores of Friesland and Groningen), or at the mouths of great rivers. The crown of these is at least 3.5 meters, and the front slope 6 to 1. Dikes of the third class, still less exposed, not on the North Sea, with a crown of at least 2 or 2.5 meters, and a front slope of 3 or 4 to 1. All these dikes have a back or land slope of at least 2 to 1, an inner berm or banquette of 4 to 10 meters, and an outer berm somewhat sloping in profile, and generally carried up one or two feet above ordinary flood tide. Dikes of the first and second classes are often built higher on the outside. The road is then placed lower down, on the back slope. Sometimes the outer slope is made concave, instead of convex, so as to give the stone pitching a flatter slope.

These remarks of Mr. Caland were made many years ago, and it is believed the dimensions now in vogue greatly exceed those given above. The author is sure that this is the case with all seen by him.

S GRAVENHAGE
Voorburg
Loosduinen
Ter Heyde
Poeldijk
Monster
Wateringen
DELFT
Naaldwijk
DELFLAND
Schipluiden
Maasland
Kethel
SCHIEDAM
VLAARDINGEN
NOORD ZEE
ROZENBURG
Oostvoorne
BRIELLE
Zwartewaal
Nieuwesluis
Rockanje
VOORNE
Heenvliet
Geervliet
Spijkenisse
WEL PLAAT
Pernis
Hoogvliet
Portugaal
Nw Hellevoet
HELLEVOETSLUIS
PUTTEN
Simonshaven
Hekelingen
Goedereede
GOEREE
Ouddorp
Stellendam
HET SPUI
Nw Beijerland
Piershil
B E IJ
HARINGVLIET
Melissant
Sommelsdijk
Middelharnis
Dirksland
Stad aan 't Haringvliet
H O E K S
Zuid Beijerland
TIEN GEMETEN
OVERFLAKKEE
Herkingen
Nieuwe Tonge
den Bommel
Oude Tonge
Ooltgensplaat
Zonnemaire
SCHOUWEN
Noordgouwe
Dreischor
Bruinisse
Nieuwerkerk
Oosterland
DUIVELAND
ST PHILIPSLAND
VOLKERAK
Dinteloord

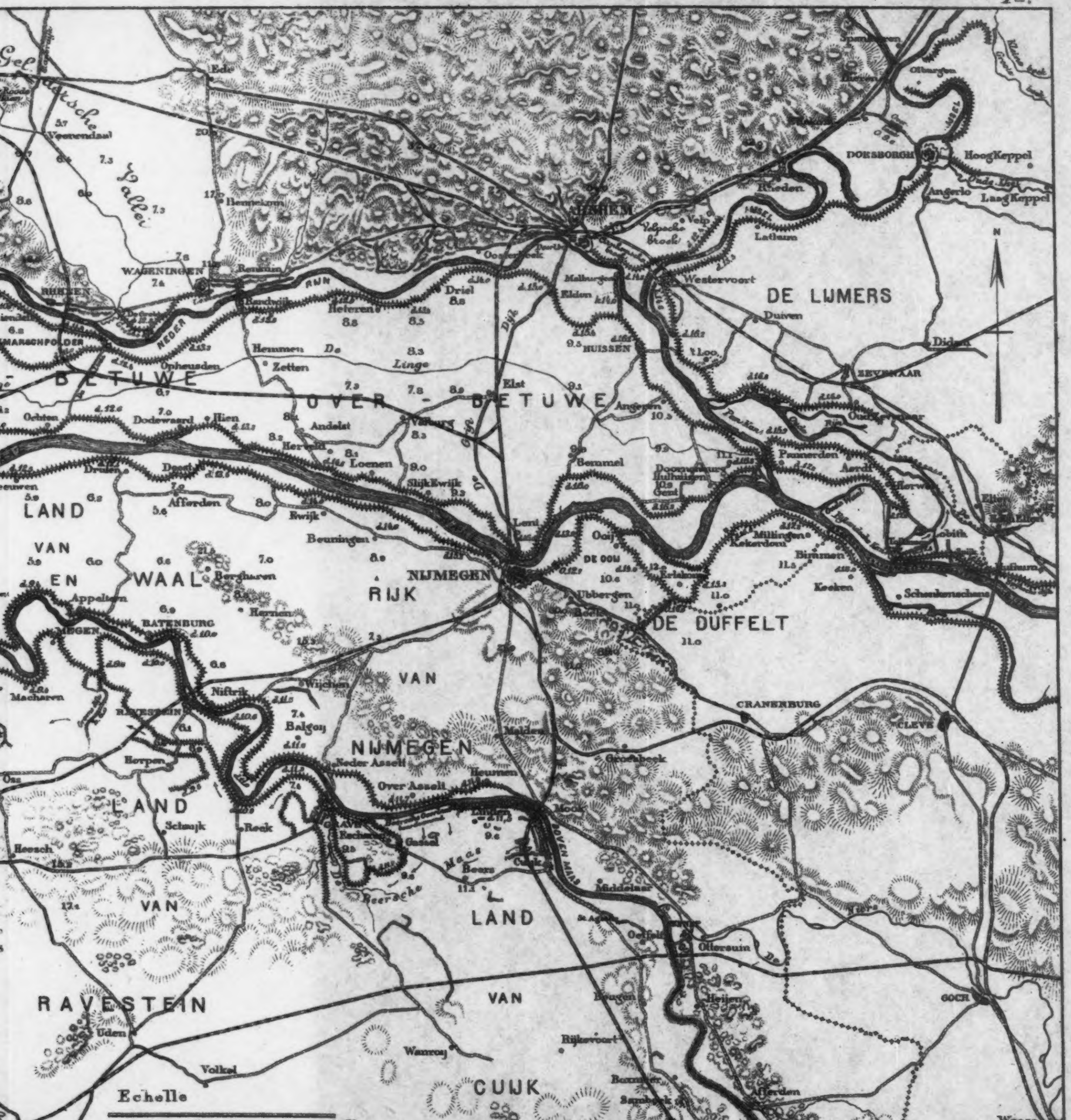
Voorburg
Rijswijk
Zegwaard
Nw Waddinxveen
Moerkapelle
Waddinxveen
GOUDA
DELFT
Pijnacker
Bleiswijk
Zevenhuizen
Zuid plas polder
Berkel
S C H I E L A N D
Schipluiden
Hilligersberg
Moordrecht
Gouderak
Haastrecht
Stolwijk
Nieuwerkerk
Prins Alexanderpolder
Rotte
K R I M P E N E R
W A A R D
Berkenwoude
Ouderkerk
Bergambacht
Ammerstole
Kethel
Overschie
SCHIEDAM
ROTTERDAM
Kralingen
Capelle (op den IJssel)
Krimpen (op den IJssel)
Krimpen (aan de Lek)
Lekkerkerk
Streefkerk
Nieuw Lekkerland
A L B L A S
Alblasserdam
Oud Alblas
Wijngaarden
Pernis
Charlois
IJselmonde
Bolnes
Slikkerveer
Ridderkerk
Hoogvliet
Poortugaal
Rhoon
IJ S E L M O N D E
Rijsoord
Heinenoord
Hekelingen
O. Beijerland
N. Beijerland
Papendrecht
Sliedrecht
Giessendam
DORDRECHT
Groote Lindt
Puttershoek
B E IJ E R L A N D
OF
Westmaas
Maasdam
's Gravendeel
Klaaswaal
Piershil
H O E K S C H E W A A R D
EILAND VAN DORDRECHT
Dubbeldam
Zuid Beijerland
Strijen
Numansdorp
Strijensas
HOLLANDSCH DIEP
Moerdijk
Lage Zwaluwe
KLUNDERT
Fijnaart
Dinteloord
Dintel
Zevenbergen
Wagenberg
Terheijden
VOLKERAK

RIVIÈRES DES PAYS-BAS.

RIVIÈRES DES PAYS-BAS.

PLATE LIV.
TRANS.AM.SOC.CIV.ENGRS.
VOL.XXVI.Nº 534.
STARLING ON HOLLAND DIKES.

Iª.



Not all of the sea-coast needs artificial protection against inundation. The western shores are naturally defended, in a great measure, by a chain of dunes or sand-hills extending, with little interruption, from the Helder, the northern extremity of the peninsula of North Holland, to the mouth of the Maas, near Rotterdam. Dunes also exist on the western coasts of the islands of South Holland and Zeeland. They are heaped up by the action of the winds, like snow-drifts, and are subject to gradual and continual migration inland, from the same cause which created them. Similar phenomena are common on other sea-coasts, notably on the eastern shore of our own continent, where the landward movement, apparently almost irresistible, has done serious damage and threatens more. In Holland the natural mobility of the sand has been counteracted, to a great extent, by planting the seaward slopes of the dunes with a species of reed grass (*Arundo arenacea*), locally called helm. This takes root even in pure sand, and holds the material in place. It is planted in tufts about 2 feet apart. The few points on the western coast where the dunes are missing, the western shores, and most of the eastern, of the Zuider Zee (the exceptions being where the uplands abut directly upon the water) are protected by dikes.

It may be mentioned, in this connection, that the term dike is generally applied by the Dutch only to works of primary importance, intended to keep out sea or river water, or which have at some time served such a purpose. Embankments of inferior grade usually go by the name of kaden or quays. The subject of protection against winds and waves will be discussed at greater length hereafter.

Second.—In considering the rivers of Holland, the reader will probably have to reconstruct his map of the Netherlands. Take an ordinary atlas and see the delineation of the water courses of this kingdom. You see that at Pannerden the Rhine splits into two branches, the Waal and the Neder-Ryn. Near Arnhem the Neder-Ryn is again divided, the Yssel of Gelderland (so called to distinguish it from another water-course further down, the Yssel of Holland) diverging toward the north and emptying into the Zuider Zee—the other branch pursuing its way, under different names, toward the west, past Rotterdam. It is still the Neder-Ryn until it reaches Wyk-by-Duurstede, where (on the map) it puts forth another branch called the Kromme Ryn, which seems to run past Utrecht and Leyden to the sea at Katwyk, becoming successively the Oude Ryn and the Leidsche Ryn in its course. At Vreeswyk, the

Neder-Ryn again sends forth the Vaartsche Ryn, meeting the Kromme Ryn at Utrecht, and the Hollandsche Yssel, which seems to run past Gouda, and to re-enter the parent stream just above Rotterdam, thus forming an island. At Utrecht, the Kromme Ryn loses a part of its water to the Vecht, discharging into the Zuider Zee. In the same basin appear the Amstel and its tributaries, also emptying into the Zuider Zee, and in North Holland the Y, which appears to be the drain of a chain of lakes lying north of Amsterdam.

Now, this does not in the least convey a correct idea of the present situation. Of the streams named above, three alone are living rivers, having an unobstructed course to the sea. These are the Yssel of Gelderland, the Lek and the Waal. All the rest have long since been cut off from all connection with the main river by dams, and have also been dammed at their lower ends, converting them into pools or canals. Some of them have been dammed several times, dividing them into different levels. They are used, in this condition, for several purposes. The dams are pierced by locks, thus still allowing them to be used for navigation, and, in fact, making them more serviceable for that end. The water is maintained at a high level, enabling them to be employed as reservoirs for irrigation and for the supply of water for stock and for drinking. By means of powerful pumping apparatus, water is brought into the elevated pools from the lower lying adjacent fields, and they thus serve for drainage. To accomplish these different purposes, their beds have been enlarged in two different ways. They have been deepened by dredging and the banks have been raised by dikes. Their storage capacity has thus been greatly increased, and their usefulness for navigation multiplied many times. They have been connected with one another by canals, forming a vast network of water-courses, all under perfect control, and all, except the main rivers, perfectly stagnant. The usefulness of the high-water level will be more plainly seen hereafter. Suffice it to say now that it serves the purposes, first, of giving greater capacity; second, of furnishing water to the higher lying lands; and third, of affording drainage, in a natural way, into the sea at ebb-tide, or into the main rivers.

The three rivers just named, arms of the Rhine, are of very different sizes. The Yssel carries about one-ninth of the total discharge, the Lek two-ninths, and the Waal two-thirds. They are all diked on both sides during their course through alluvial ground, which is about

equivalent, roughly speaking, to their course from the first point of separation, namely Pannerden, below Emmerich, to their mouths. The Maas is diked, with some exceptions to be noted, from about Mook, a little above Grave, to near Woudrichem, where it empties into the Waal. (See Plate LIV.)* The Schelde is diked from above Antwerp. Very little of this river, however, is in Holland.

The river dikes are much less massive than the sea dikes, and are of very variable dimensions, according to the material of which they are built, the foundation on which they rest, the extent and value of the country which they protect, the resources of the local organizations which maintain them, and many other considerations. They, also, like the sea dikes, are exposed to wave action. The rivers are wide and have long bends, through which the winds have full sweep. The destructive force of the wind is found to be specially great when it blows up stream. It is necessary then to make provision against this danger. River dikes are exposed to other perils, some general to all dikes, some peculiar to rivers, some incident to particular rivers, which cause them to be built in forms very different from those which might have been expected.

The sea dikes are constructed of such superfluous strength that they are not generally instructive as a study. The river dikes have not been built with the same lavish expenditure. They bear the marks of having been evolved by a gradual process from small beginnings, and it is evident that economy has been studied in their construction and maintenance. For these reasons and also because they were closely analogous to those which the author had to look after at home, he gave them much more attention, and inspected considerable stretches of them personally.

Before proceeding to the consideration of the river dikes as they actually exist, it will be proper to examine a little the principles of dike building. In Holland, all elevations are referred to "Amsterdam Datum," expressed by the abbreviation "A. P." (Amsterdamsch Peil). It is supposed to have indicated mean flood at Amsterdam when the Y was open. The Y is now a part of the North Sea Canal and is dammed

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* This plate is a copy of the map of the "Rivers of the Netherlands," appended to the pamphlet entitled "Les Voies de Navigation dans le Royaume des Pays-Bas," published under the auspices of the Dutch Government, for the Manchester Congress of Internal Navigation, in 1890. The figures indicate elevations above Amsterdam Datum. The letters *d* and *k*, prefixed to figures, mean dike and *kade*. Where no letters are prefixed, the elevation is that of the natural surface.

off at both ends. This mean flood height is shown by a certain bolt in the front wall of the Bourse at Amsterdam, and also by two other bolts in different parts of the city. Other data are high water (H. W.), low water (L. W.) and "Mean River" (M. R.). This last signifies the mean of the stages from May 1st to October 31st (the six summer months), for the last decennium that ended in a multiple of 10—for instance, from 1880 to 1890.

It might be supposed that the rules prescribed for the construction of earthen reservoir walls would be applicable to dikes, but it is not so. There are local and economical considerations which forbid the use of the precautions usually taken with reservoir embankments and necessitate the employment of others in their stead. Dikes, in short, are cheap, low and very long reservoir-walls, designed to contain water for a limited time. They cannot generally be built on firm or impervious foundations and must be made of the material which is closest at hand, which may be good or bad, but which is usually abundant. They are almost always placed directly upon the surface of the ground. In other words, both the embankment itself and its foundation must depend upon the constantly varying nature of the soil. These are the ruling conditions to which the construction must conform. The alluvial soil of Holland, like any other alluvium, is composed of strata of various qualities of earth, differing in density, in tenacity, and in their capability of being made water-tight. All natural soils are more or less porous and transmit water pretty freely; but some still retain their quasi-fibrous texture, and have their tenacity not impaired, or at least destroyed, by being infiltrated. Others become entirely disintegrated, and some almost lose their solid quality and run like a liquid. In consequence of their porosity, natural soils adjacent to water-courses become saturated to a long distance and nearly to the very level of the water itself.

Now, it is perfectly possible to construct a good and tight dam or dike out of poor material, by devices familiar to engineers, such as building in thin layers, rolling, watering, ramming or tamping, puddling, and the like. But if the natural soil be porous to a high degree, there will be leakage under the embankment to an extent which may be very inconvenient and even extremely dangerous. The water which thus transpires through the soil is called by the Dutch "leak-water," and by the Americans of the Mississippi Valley "sipe-water" (pronounced *seep*). It is sometimes enormous in quantity. If the soil be of a fibrous

and tenacious kind, so that a certain continuity and coherency are preserved even in a moist or wet state, the evil will probably be confined to mere leakage, which will be embarrassing or damaging in proportion to its quantity, its duration and the means of getting rid of it by drainage. But if the soil be composed of loose and independent particles of small size, it may become exceedingly unstable and even mobile when saturated with water. A fibrous or honeycombed soil, though never so porous, yet presents, as it were, a network of capillary tubes, which afford a strong frictional resistance to the flow of water and diminish the hydraulic head by so much. But earths of the second kind permit their particles to be perfectly enveloped by the liquid and held in suspension by it, in proportion to their smallness and lightness, perhaps also to the cohesive union between the water and the particles, which is different in different earths. Hence result a variety of treacherous and semi-fluid soils, commonly classified together as "quicksands," which instead of remaining in place and resisting the passage of water, are actually carried by it and are, as it were, incorporated with it. It follows that such soils will transmit the pressure of the external water with comparatively small loss. It is evident that if the water stand very high against the embankment, the pressure transmitted under the bank will be exerted upon the layer of strong soil, if such there be, overlying the quicksand, and if this be thin, will "blow it up," as it is called, thus knocking the foundation from under the dike or levee, and causing the destruction of the latter, as shown in the sketch. This is no chimerical

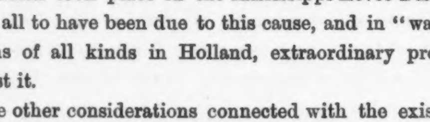

FIG. 1.

or merely speculative danger, but a very real and threatening one. The five breaks which took place in the Mississippi Levee District in 1890, are believed all to have been due to this cause, and in "water-turning" constructions of all kinds in Holland, extraordinary precautions are taken against it.

There are other considerations connected with the existence, under the dike, of a semi-fluid mass, that deserve attention. "If a sufficient quantity of water finds its way into the center of a bank that has been put together in a comparatively dry state, it will rise and soak into the

earth until at length what was a solid mass becomes semi-fluid, settles into a smaller space than it before occupied, and as a consequence will leave a vacuity above it. The inevitable result is the subsidence of the superincumbent earth; but instead of resting, as at first, on a resisting material, it floats, so to speak, on the semi-fluid mass underneath, and having little or no friction to overcome, slips away to a lower angle than it before stood at."* In the construction of great dams for reservoirs and the like, provision is made against this danger by carrying the work down to bed-rock or at least to impermeable strata. This is not possible in dikework, because dikes are nearly always built in alluvial soils, where rock is at an infinite depth, and even impermeable strata may lie so far beneath the surface as to be practically inaccessible when economical conditions are considered. Nevertheless, if such precautions are indispensable to safety, they must be taken, at whatever expense, or the dike system abandoned. Fortunately, means have been found of dispensing with deep foundations, considering that dikes are usually of very moderate height, and the head consequently not excessive and of only temporary duration.

For, first, it is not by any means universally the case that sandy strata exist at a short distance below the surface. It is obvious that if the top stratum of clay or strong loam be of tolerable thickness, say 6 feet, it would balance a hydrostatic pressure of double that height, and by so much the more a hydraulic pressure, diminished by friction and fall. If, therefore, the water-bearing stratum be deep and the dike not very high, an embankment strong enough, in itself, may also be safe from beneath.

Secondly, if the stratum from which danger is apprehended lie close to the surface, it is clear that the thinness of the strong top soil may be supplemented by artificial means. To this end, a layer of several feet of earth may be placed upon the natural surface on the inner or land side of the dike, to serve as a counterpoise to the column of external water. As to the dimensions of this banquette, as it is usually called,† it is hard to lay down any rule. It is a matter, in fact, that has been regulated wholly by experience. It will be seen that the width, no

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* "Jacobs on Storage Reservoirs," page 84, Van Nostrand's Science Series.

† The Dutch call it merely a *binnenberm*, or inner berm, but it seems desirable to make a distinction between a berm, which is properly a portion of the natural ground left untouched, and a piece that is artificially raised above the surface.

less than the height, has to be considered. The upward pressure of the water in the soil extends to an indefinite distance, but, when far removed from its source, is so diminished by friction and fall that it ceases to be dangerous. It will also be evident that a banquette, or an extension of the base, on the front or water side of the dike, will be serviceable to this end, by removing the source to a greater distance. Thus, by adding the exterior banquette *A, B, C, D,* we have transferred the maximum head from *A* to *B*, and have thus given the subterranean current a

FIG. 2.

longer distance to traverse. Accordingly, we find numerous instances of both interior and exterior banquettes on the Holland dikes, of all possible dimensions, from 3 to 10 feet high, and from 20 to 100 feet in extreme width. The inner banquette is by far the predominant form, and, in fact, if there is only one, it is almost always on the land side—the outer, if any, being added as a supplement or additional safeguard. The new South Linge dike contains several banquettes of the largest dimensions. Their cross-section is usually a long convex segment, the extreme altitude being, perhaps, from one-fifth to one-tenth of the base.

In place of a banquette, a somewhat ingenious device is occasionally employed, evolved by necessity or emergency, doubtless, during the high-water season, as it has been on the Mississippi. A low interior bank is thrown up, at a distance of 20 or 30 feet or more from the main dike, and connected with the latter by wings, thus forming an inclosed space, which is allowed to fill with sipe water. The latter exerts a certain counter-pressure against the external river water, thus relieving the main dike of a part of the lateral strain and also the weak interior berm of a part of the upward pressure. This is a very common device in America, especially for the temporary cure of bad leaks, and several places were seen where it had been employed in Holland. The author was told that it was a well-known expedient there.

It may be a matter of surprise to the reader that no direct means have been mentioned hitherto of cutting off the leakage under the dike, or at least a portion of it. Such means have been tried, but their efficacy is not universally admitted. In the Valley of the Mississippi it is the almost invariable practice among the levee engineers to put what they

call a "muck ditch" under their embankments, that is, to excavate a portion of the natural soil and to replace it with strong well-tamped earth, clay if possible, thus causing a projection, as it were, of the embankment into the earth, after the manner of a tongue and groove joint. The office of this adjunct evidently is to supply, as far as may be, the want of a foundation extending to an impermeable stratum, and to stop at least a part of the leakage, by substituting a tight for a porous soil for a part of the way. It also gives the water a somewhat longer distance to traverse. It is thought to be especially "indicated," as the physicians say, in sandy soils, and in those permeated by roots and the like. Occasionally, sheet piling has been used to a limited extent, and it has been proposed to put in longitudinal diaphragms or vertical walls or cores of cement or concrete. These latter precautions have the fault of being very expensive, and they have never been given a fair trial in this country. No more have they in Holland. Even muck ditches, though known to the Dutch engineers under the name of *Klei-kisten*, clay boxings as it were, are not much favored by them. They think that they do not go deep enough to do any material good, and cannot be made to do so without great expense. What is the use, they say, of going 6 or 8 feet into a sand stratum which is 20 or 30 feet thick? Nevertheless, the experience of the American engineers is that muck ditches, when of considerable dimensions, well filled and tamped, perform an important part in arresting sipe water, at least in the immediate neighborhood of the dikes, and that is the most dangerous point. In Mississippi, the new levees, built since the flood of 1890, have muck ditches 12 feet wide at the top, 6 feet wide at the bottom, and 6 feet deep. They were unusually dry during the flood of 1891, and so was the land behind them, though previously well known to be very much affected by sipage. The Dutch engineers themselves show that they attach some consequence to this principle, by adopting and insisting on very similar precautions in the case of culvert and lock floors, as will be seen hereafter. It may be noted here that the Dutch never use a puddle wall or any similar device, or any diaphragm of timber, concrete or other material in their dikes. The immense dikes now building for the new mouth of the Maas are furnished for part of their course with muck ditches of considerable dimensions, averaging about 4.5 meters wide at top, 1.5 at bottom, and 3 meters deep. For about two-thirds of the line, however, they are not used.

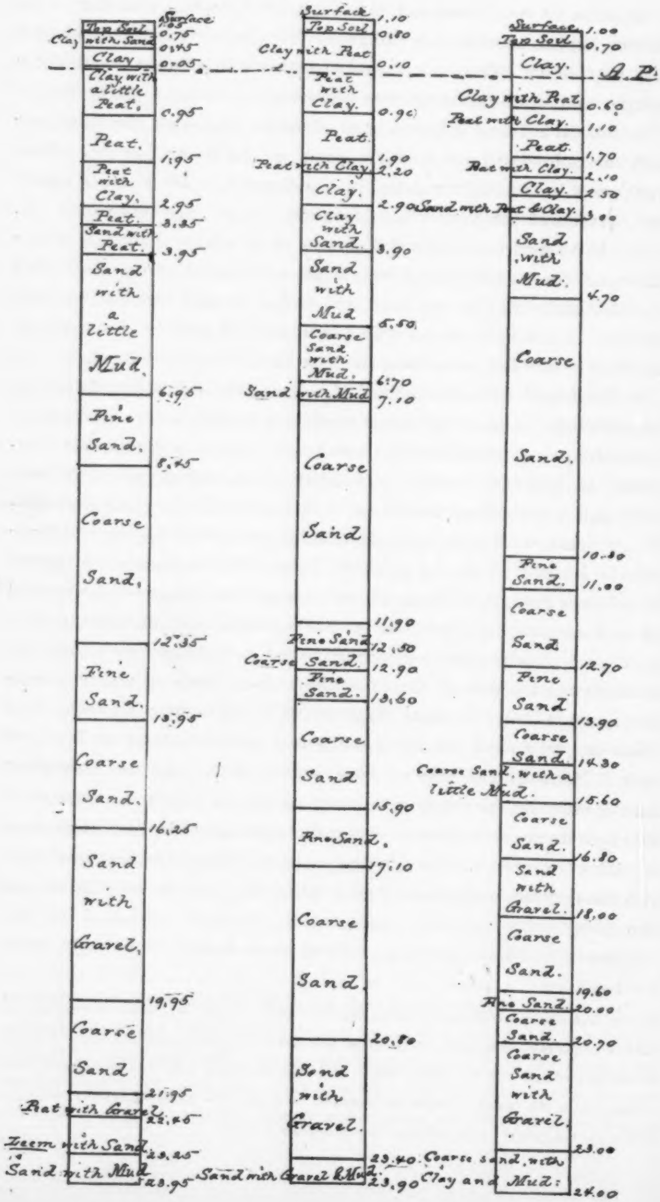
In America our worst soil is sand. In Holland, what they most distrust is peat, or what they call veen. This has already been spoken of as a very light, rotten, compressible soil, which absorbs water like a sponge, and doubtless transmits hydrostatic pressure pretty freely. This material is found in strata of considerable thickness, as will appear from the following borings at Vreeswyk, on the River Lek (one of the branches of the Rhine), furnished by the courtesy of Mr. Kemper, one of the engineers of the Amsterdam-Merwede Canal. (See next page.)

It will be seen that under 6.5 feet or so of clay and mould, with a little peat, there exist successively strata of 3 feet of pure peat, 6.5 feet of peat mixed with clay and sand, and 60 feet of sand, alternately coarse and fine, occasionally mixed with a little mud or gravel. Accordingly, the dikes of the Lek are among the most dangerous in Holland.

In Baedeker's "Guide Book to Belgium and Holland,"* it is stated that "the first care of the constructor of dikes is to lay a secure and massive foundation, as a preliminary to which the ground is stamped or compressed in order to increase its solidity." The author was not able to verify this observation, though he questioned every engineer he met—among them several of acknowledged eminence. On the contrary, so far as could be learned, no special pains are taken with the foundation beyond the ordinary precautions to secure an intimate union between the natural soil and the new bank—and the possible preliminary operation of displacing a stratum of peat by throwing in sand, as will hereafter be noticed. As to the construction of the dikes themselves, there are pretty minute directions in the "General Regulations" (Algemeene Voorschriften) which are published for the guidance of contractors of all kinds of work. There are two sets of these, one published by the Waterstaat and the other by the corps of military engineers. Each is a volume of 250 pages or so, and contains standing regulations for the performance of work of every sort. Each is made a part of all contracts entered into with the respective organizations by whom they are issued. There are also many very practical and useful precepts contained in the "Manual" of Storm-Buysing.† From these sources principally, some

* Page xxviii.

† D. J. Storm-Buysing, Handleiding tot de Kennis der Waterbouwkunde, voor de Kadetten van den Waterstaat en der Genie. Breda, 1844-45. Two volumes, with atlas. A later edition was published in 1868. This work has not been superseded, though it appeared so long ago, and is still the recognized authority. There is a vast encyclopedic work in course of publication which will, however, eclipse everything else—the "Waterbouwkunde" of Professor Henket and others. Eight volumes of text and eight of plates have already appeared, and there are ten more of each to follow. The price will be about $200. The Dutch Waterstaat corresponds to the French "Ponts et Chaussées," and the term Waterbouwkunde embraces not only canals, dikes, etc., but roads, bridges, railways and land drainage. Henket's collection has not yet got so far as dikes—or had not last August.


Surface
Top Soil
Clay with Sand
Clay
Clay with a little Peat.
Peat.
Peat with Clay.
Peat.
Sand with Peat.
Sand with a little Mud.
Fine Sand.
Coarse Sand.
Fine Sand.
Coarse Sand.
Sand with Gravel.
Coarse Sand
Peat with Gravel
Leem with Sand
Sand with Mud
1.55
0.75
0.45
0.05
0.95
1.95
2.95
3.25
3.95
6.95
8.45
12.35
13.95
16.25
19.95
21.95
22.45
23.25
23.95
Sand with Gravel & Mud
Surface
Top Soil
Clay with Peat
Peat with Clay.
Peat.
Peat with Clay
Clay.
Clay with Sand.
Sand with Mud
Coarse Sand with Mud.
Sand with Mud
Coarse Sand
Fine Sand
Coarse Sand.
Fine Sand.
Coarse Sand
Fine Sand.
Coarse Sand.
Sand with Gravel.
1.10
0.80
0.10
0.90
1.90
2.20
2.90
3.90
5.50
6.70
7.10
11.90
12.50
12.90
13.60
15.90
17.10
20.80
23.40
23.90
Surface
Top Soil
Clay.
A. P.
Clay with Peat
Peat with Clay.
Peat.
Peat with Clay.
Clay.
Sand with Peat & Clay.
Sand with Mud.
Coarse Sand.
Fine Sand.
Coarse Sand.
Fine Sand
Coarse Sand.
Coarse Sand, with a little Mud.
Coarse Sand.
Sand with Gravel.
Coarse Sand.
Fine Sand.
Coarse Sand.
Coarse Sand with Gravel.
Coarse sand, with Clay and Mud.
1.00
0.70
0.60
1.10
1.70
2.10
2.50
3.00
4.70
10.80
11.00
12.70
13.90
14.30
15.60
16.80
18.00
19.60
20.00
20.70
23.00
24.00

remarks have been compiled on the construction, maintenance and defense of dikes which it is hoped will be found instructive. Where they are not consistent with the present practice, so far as this could be ascertained, they have been corrected.

Dikes should first be high enough, that is, 0.5 to 0.6 meter above the highest known water mark. (This margin has been increased to 1 meter.) They must be strong enough to resist the utmost force which the water can exert, and must to this end have the section of a trapezium, and must be composed of good, tenacious earth, which shall cohere, not only with itself, but with the ground whereon the dike rests. The crown may be from 0.5 meter to 8 meters wide, the inner (or land or back) slope 1½ or 2 to 1, the outer (water or front) slope from 2 to 8 or 10 to 1, though sometimes the back slope may itself be flat. There should be berms both inside and outside, which should usually be simply the natural surface, but which may be partly artificial, to compensate for inequalities of the ground. There should be a foreshore of varying breadth, according to the dimensions of the dike and the nature and degree of its exposure. For small rivers, the minimum may be 75 meters; for great rivers and for sea dikes, from 150 to 200 meters, which may in unfavorable cases be increased to 375 meters. Traverses 6 meters wide at the crown should be left across the borrow-pits 100 meters apart, to promote the silting up of the pits, and to serve in case of future enlargement and repair.

The trace of the new dike should of course have regard to economy of material and capacity for protection. Its general direction should run nearly parallel to that of the stream, but should avoid, as much as possible, exposure to the most destructive and prevailing winds. But especially the fitness of the foundation should be regarded, and good, high ground selected, free from creeks or sloughs. Sharp angles are to be condemned—especially re-entering angles, because they make basins in which the wind has full play to raise the water. Where changes of direction occur, they should be made by a curve, uniting the two tangents.

The criterion of height must be the recorded elevations attained by great floods. These are usually given as in still water, and freed from the disturbance of wave action. An allowance must therefore be made for this, varying according to the exposure, which of course is greatest for sea dikes and least for rivers. On some of the Zeeland islands it amounts to 6.5 meters. At Westkapelle it is 5.5. The

height of waves is less when there is a broad foreshore and where the water is shallow, and it is less with a flat than with a steep slope.

A wide crown is an advantage, even though the dike be not habitually used as a roadway. In time of danger, it may serve as a means of transport for material, and especially it may be of incalculable benefit in case of inundation when the ordinary roads are submerged. We should, therefore, give to the crown of dikes not generally used as roads a breadth of at least 3 meters, and to those which are so used a breadth of 5 or 6 meters. (Add to this, that a wide crown affords a base whereon to put a temporary topping in case of extraordinary floods, and also may furnish the material for such a work. It gives a secure and convenient foothold for men engaged in high-water work, in protecting against storms and the like—and affords space for the storage of brush, sacks, wheelbarrows and other high water material.)

For the inner or land slope no greater inclination is necessary than that which is demanded by the natural angle of repose of the soil. (*Per contra*, such slopes sometimes slough, if saturated with water, or if the ground beneath them be porous and wet.) Nevertheless, experience teaches that slopes of less than 2 to 1 are unfavorable to the growth of grass. This ratio then is prescribed.

If dikes had nothing but hydrostatic pressure to stand, and if the material were uniformly tenacious and sound, the dikes might have a triangular cross-section. But first, earthy materials are never homogeneous, and the method of construction does not insure uniform density or compactness; and, secondly, the work has to resist the shock of waves, which is the most common cause of destruction.* The force of the shock of water or of floating bodies, as of ice, against the slopes is in proportion to the sine of the angle which the slope makes with the horizon. Therefore, a flat slope withstands such action better than a steep—which is consistent with experience.† Ice, however, is never brought by low water, but always by the flood. Therefore, the lower portion of the slope may be steeper than the upper. So, also, the lower part, being much under water, cannot be protected by sod, but must be faced with stone or other costly material. Hence, on the score of economy, we arrive at the same conclusion.

This precept has been carried into execution in most of the great sea

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* Storm-Buysing, Waterbouwkunde, 1, 359-60.

† Beekman says that flat slopes are a comparatively modern invention.—De Strijd om het Bestaan, p. 282.

dikes that were inspected—the lower slope being generally 6 to 1 and the upper slope broken into portions that became gradually flatter, till, in the case of the Westkapelle dike, they reach 17 to 1. Economy in the use of basalt protection has led to the adoption of broken slopes also in the case of the river dikes, but here the cross-section is concave and not convex, thus:

FIG. 3.

The reason of this is that by reason of the rapidity of the rise at moderate flood stages, and of the shallowness of the water at such a stage (owing to the foreshore), the long sodded slope *A B* is sufficient up to the point *B*. Briefly, it is found by experience, on the Mississippi, that wave-wash is mostly confined to 2 or 3 feet below the high-water line. Above mean flood the damage would be severe, so here the basalt revetment is placed; but to save cost it is made very steep. Many cases of this kind were met. There is generally a row of small oaken piles, called *perkoenpalen*, at the bottom of these steep pitchings (and even when they are not so steep), to keep the stone from sliding. Sometimes there are several rows of *perkoenpalen* at intervals between the stones. As the Dutch rivers remain at extreme high-water mark only a day or two, the basalt revetment is not usually carried to the top of the slope.

The material of the dike should, if possible, be clay, and should be taken from the outside. If clay cannot be had in that situation, then resort must be had to the inside. Sand has little cohesion and does not make a strong and water-tight dike. Peat has too little specific gravity, often less than water, and will not answer well. Mould or arable ground, though not so good as clay, is far better than sand or peat, packs closely, and is especially suitable for dressing slopes that are to be sodded, as grass grows finely in such soil. Clay cannot usually be had in sufficient quantity to build the whole dike. It must therefore be combined with other material. This may be safely done, provided the precaution be taken to put the best and purest clay in and next to the front slope, while the poorer earth is placed in the body of the dike.* There are examples of dikes that consist of very sandy material, with a dressing of only 1 meter of clay, yet they turn water excellently. But it is easy

* Algemeene Voorschriften (ed. 1882), p. 6.

to be seen that such a covering must be carefully treated and protected from injury, as, if the poor material be exposed, it cannot be trusted to exclude the water.

In the putting up of embankments, as well as in excavations, the grass must be taken out in regular sods and piled on one side. The base of all earthworks must be cleared of all mud, filth, straw, sedge, brush, rubbish, etc.—either all at once or in sections, as the execution of the work may require. When the embankment is designed to keep out water, the earth must be broken with a spade or plow to the depth of 0.2 meter (say 8 inches), and chopped fine. This applies also to existing earthworks to which the new work is to be joined. The embankment must be provided, in addition, with V-shaped ditches, at least 1 foot deep and wide, at the foot of each of the slopes, and with trenches of the same width and depth, at a distance apart of at least 1 meter, to the satisfaction of the Direction.* The new earth will not settle at once to the density which it will ultimately acquire, but will undergo a process of shrinking from the pressure of its own weight and the evaporation of the water which it contains. Further, the natural soil under the dike will undergo a greater or less compression, until an equilibrium is reached. Therefore the dike must be built higher than the required grade by an amount, varying according to the material and the mode of construction, from one-seventh to one-twentieth of the height (one-fifth to one-tenth in the Mississippi practice).

To obviate too great shrinkage, the embankment must be carried up in layers, level longitudinally and rather sloping transversely, of a thickness of 0.3 to 0.4 meter if carts are used, and 0.2 to 0.3 meter if built with wheelbarrows, according to the quality of the earth. If the work be done with locomotives the thickness of the layers is to be determined by the Direction.† (Scrapers, either drag or wheeled, seem to be unknown in Holland—at least, great difficulty was experienced in explaining what they were.) Horses and carts are greatly to be preferred to wheelbarrows, and should be used, if possible, at least in part. The teams must not all travel the same road, but must change their tracks constantly. The earth must be freed from foreign matters, and properly broken fine, and if the Direction requires it, tamped with heavy rammers. The number of tampers is regulated by the Direction according to the quality of

* Algemeene Voorschriften, p. 4.

† *Ibid*, p. 5.

soil. As a general rule, there must be one tamper to four shovelers. If the nature of the ground requires more tampers, it will be so provided in the specifications. If the earth is tamped by horses, they must be managed by grown persons. (Old cavalry horses are generally used.) The embankment must not be begun until all creeks, ditches and gullies falling within the work are divested of mud and vegetable matter, their sides dug away to a slope of 2 to 1, and they filled with well-tamped earth, with a convexity of at least one-eighth of their depth.

Unless otherwise specified, borrow-pits must not be less than 10 meters from the foot of the slope, and their sides must have such an inclination as is satisfactory. At intervals of 100 meters, cross-berms or traverses must be left, 6 meters broad and of sufficient slope. Borrow-pits on the land side must be dug regularly and under the orders of the Direction. The slopes must be flat, and the small dams or balks left after completion removed. Private property must never be trenched upon, unless by written permission or by order of the Direction. Slopes must be dressed to the line and deficiencies properly made good. These works must be entrusted only to experienced earthworkers or slope dressers.*

The sods which have been removed from the base and piled at the sides are now placed upon the slopes regularly in rows, beginning at the bottom. They are closely fitted, struck in place with heavy wooden paddles and covered with fine earth. If sods cannot be had, the dike is sown with clover seed. A good close sod is the best protection for dikes which have any considerable foreshore, and it is important to preserve it in good condition. Judicious pasturing is the best means to this end. Calves and sheep should not be allowed, because they graze too closely, nor horses because their shoes cut the sod. Pasturing should not be begun until the second or third year, and not continued after the first of October. The dike will become more compact, the cattle will tramp together all mouse or mole holes, and by manuring will promote the growth of the better kinds of grass.† Low places and cracks should be filled in the spring with fine earth.

Trees on dikes are highly prejudicial. They prevent the dikes from becoming thoroughly dry. Grass does not grow well in their shade or under their influence. They are shaken even to their roots by heavy

* Algemeene Voorschriften, pp. 6–7.

† Storm-Buysing, Waterbouwkunde, i, 365–6.

winds and the ground loosened accordingly. (Add to this, that there are frequently cavities under the arch of the roots of large and especially old trees, and that considerable streams of water may be conducted through the dike by means of the lateral roots. The latter are subject to decay and then constitute formidable channels. This salutary precept is often violated. Many important dikes have double rows of trees for long distances, for the purpose, apparently, of giving shade to travelers. Impunity has brought about recklessness which may possibly result in disaster in time of some great flood.) The planting of trees outside a dike at a safe distance, is to be encouraged by all means, as a protection against waves and ice. (A thick growth of small timber outside a dike is undoubtedly an effectual safeguard against even heavy storms. A thin and scattered growth, even though of considerable width, is not of much value.)

Ramps for road-crossings should have a slope of at least 12 or 14 to 1, and a crown of 8 feet. For important roads the slopes should be still flatter and the crown 12 or 14 feet. In weak soils the sod should not be broken, so as to preserve as much as possible the toughness of the upper stratum. By increasing the width of the base we may distribute the pressure over a greater surface and decrease the danger of sinking. To this end the lightest soil should be placed under the crown, where the mass is greatest. To obviate partially the defect of an imperfect union between the old and new earth, we may break the ground for 2 or 3 meters from the foot of each slope. The dike should be put up slowly and regularly, so that the settling may be as uniform as possible without cracks. Should these means be insufficient, mattresses must be used. (Such is not now generally the practice. See *post.*) Flat slopes on the land side are prescribed in three cases: first, when it is necessary to give a very broad base; second, when the nature of the ground compels a steep slope on the front, and third, in the case of overlaten, of which more hereafter.

Bank protection is frequently necessary for the safety of dikes. It should be resorted to before the foreshore is too far gone; for though the protection of the bank be expensive, that of the dike and the bank together is still more so, and it is dangerous besides. There should be no undue haste about it, however, for the river may take a more favorable turn and save us the trouble. Damage to a bank may result from two causes: from winds and from currents, or from both combined.

Winds and the waves which they produce affect the upper portion of the bank alone, without injury to the lower portion or beach—nay, the latter may increase at the expense of the former. The current, however, always works in deep water, scours out the beach, and sometimes undermines those dikes which have but little foreshore and causes them to fall in. The repair of such accidents is always costly and often precarious, and it frequently happens that after all our trouble we have to build a new line. For defense of the upper bank against waves, doubtless direct revetment by stone or other suitable means is the best. For the prevention of erosion by currents, hoofden have been found efficient. (Hoofden, literally heads, are of very general use in Dutch engineering. The term hoofd is applied to any spur dike, but especially to the elaborate constructions which are designed to resist the action of the winds and currents of the sea. They are found at the Helder, at the Pettemer and Hondsbossche sea-works, at the Hoek van Holland, at Westkapelle (where there are miles of them) and elsewhere. They are built of clay, faced with stone and with or without piles driven into them. They are mostly intended (the stone part at least) to be submerged at high water. They have a very long seaward slope (at the Helder about 40 to 1). The strongest and most elaborate that were seen were at Westkapelle, and details of them will be given when that place is particularly described. For bank protection in rivers hoofden should extend to the deepest part of the stream, or as near thereto as practicable. To this end zinkstukken* should be constructed, from 0.6 to 1 meter thick, and ballasted with stiff clay and stone. A length of 180 meters can be given to such a mattress, which length, however, though measured from the low-water margin, may yet not reach the deepest part of the channel. Yet even though it fall a little short, it will still be serviceable. Should it be undermined at the foot and settle or slide a short distance, this can be made good by a shore-mat at the landward end.†

Zinkstukken cannot well be made more than 12 to 16 meters wide. To cover the whole bank by such means would undoubtedly be a perfectly effective plan for preventing erosion, but it would be very expensive. For this reason, instead of placing the mats in actual juxtaposition, we lay them at intervals of about half their length and then carefully observe the effect. Should more erosion ensue, the spaces

* See *post*, p. 644.

† Storm-Buysing, Waterbouwkunde, i, 372.

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* See *post*, p. 644.

† Storm-Buysing, Waterbouwkunde, i, 372.

must be shortened or intermediate mats sunk. From the low-water mark up, in the prolongation of the axis of the mat, the spur proper is built up to high-water mark. A greater height would be expensive and very seldom useful. The direction of the spur should be at right angles to the dike and to the direction of the stream. If the stream and the dike are not parallel, there should be an elbow in the spur. Spurs should not be put in independently, but according to a regular and well-considered system. Concave curves are to be avoided, as affording more points of attack to the current. The ends of the spurs should therefore lie in a right line or a convex curve. (This is not according to our practice.) The upper-bank spurs may be spaced further apart than the sub-aqueous mats, at twice or even four times the distance. It is better to have too few than too many, as the deficiency may easily be supplied if necessary. The cross-section of the spur is not a matter of great consequence. It should be flat rather than steep, as experience shows that in the latter case the shock of the water causes holes of greater or less depth, while the flat spurs become buried in the sand and thus give no trouble in the maintenance. Spurs are usually constructed of clay, protected against the action of the water by a facing of straw-mat,* brush or stone, or simply by brush and broken brick, upon which heavier stone is sometimes placed.

Some banks do not suffer erosion from the water, but, on the contrary, grow by accretion. They are raised gradually to the height of slack tide, when vegetation begins to start. After that time they are covered only by higher and mean floods. Consequently, they grow more slowly, and can never, from the nature of the case, exceed mean flood height. When they reach this level they can generally be reclaimed profitably by dikes. Such reclamation is common at this day in Zeeland, North Brabant, Friesland and Groningen. The process can be greatly expedited by artificial means. These accretions are of much moment to the safety of the dikes, and the higher they are, the more valuable are they on that score. Therefore, every encouragement should be given to such endeavors. In Friesland, they begin the work by placing small screens or hurdles, to turn aside the current, and prevent it from running across the territory to be reclaimed. As soon as the mud is sufficiently dry at ebb, the tract is divided into small lots, some 5 meters broad, by ditches cut perpendicular to the bank, 1.5

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*See *post*, p. 593.

meters wide at top, 0.6 meter deep and 0.3 meter wide at bottom. These ditches are given a length not exceeding 250 to 300 meters, and they are shallower next the bank than inland, so that the muddiest dregs of the water do not run off, but are retained. The accumulated silt is then thrown out into the middle of the lot, and distributed over it. Generally, the first year after this operation, young sprouts begin to show themselves upon the lots, and in two years the ditches are filled with silt. They are then cut out again, and the earth thrown on the land. After a few years two lots are united into one, and a cross-ditch dug for drainage. The same process is then repeated on the side next the sea.

In Zeeland, for a like purpose, so-called silt-catchers ("slik-vangers") are thrown up, being small levees with a height of 0.2 to 0.5 meter above the ground, with a slight slope to the front. They are placed at a distance of 20 to 30 meters apart, and have broad flat slopes of 3 or 4 to 1. They are covered over their whole width with a straw mat, to resist the flow of water. They are joined to one another, near the ends, by a so-called puddle-berm ("plasberm"), which is a layer of brush with the tops turned landward, fastened with three rows of wattled stakes. This puddle-berm holds the silt without confining the ebb water. This process is equally effective with that of the Frieslanders, but is more expensive.

A good foreshore is a great protection to a dike, but it is not always sufficient to reduce the size and force of the waves within such a limit that a good sodding will withstand them. If there be no foreshore, so much the worse; for the violence of the waves increases with the depth. Now, there are many localities where the dikes abut directly upon the sea—the foreshore having been scoured away or beaten away by storms. In these situations the dikes would speedily follow the example of the shore, were not artificial means taken to prevent it. It has already been said that against wave action direct protection is the proper remedy, though hoofden are sometimes powerful auxiliaries. (They seem indeed to be considered essential, in the present practice, in cases of severe exposure.) In the first place, the most destructive part of the storm shocks is directed against that portion of the bank which lies above low water. It is therefore easily got at, and revetment or other suitable device can be applied without difficulty. Secondly, the winds are variable in direction and the hoofden are fixed. They may, there-

fore, be enfiladed, as it were, and will then be useless. (As now used, they are placed perpendicular to the most destructive winds. For instance, at Westkapelle the northerly winds are the most dreaded. The hoofden, therefore, run nearly east and west. The same is approximately true of the Hondsbosch hoofden and of the Delfland hoofden, which protect the Hoek van Holland and the mouth of the new waterway from Rotterdam to the sea. They extend far enough and are spaced far enough apart to mask one another. They probably serve also another important purpose in modifying destructive littoral currents engendered by the north winds or the tides.)

Various methods of direct protection have been used, and are still actively practiced. In severe cases pilework and stone are the means most depended on ; in others, recourse may be had to straw and brush, especially for temporary purposes. Pilework, when employed, as it usually is, for the defense of important dikes, is elaborate and thorough, and exhibits considerable variety in its several types. The principle which seems to have met with the most acceptance is that of a double row of piles, parallel to the trace of the dike, properly braced back, and the interval between the rows filled with brush, broken brick, and finally with large and heavy blocks of stone. The piles are driven as close in the row as possible, and spiked to waling-pieces. The objections to this type seem to be the vertical or nearly vertical position of the piles, which invites the greatest amount of shock and causes the greatest possible undertow, whereby the foot of the pilework is apt to be scoured out, unless there be a considerable rip-rap of stone there—the liability of wood to decay—and, in salt water, the exposure to the attacks of the teredo. The first objection may be obviated by spiking inclined timbers to the piles, or by rip-rap as aforesaid. In Holland wood appears to last very well. It is said that the average lifetime of an oak or fir pile is at least thirty years. As for the teredo, it is only bad on the sea-coast proper, and then only below mean tide-water. It hardly frequents the Zuider Zee at all, and is not found in brackish waters. So pilework is still much in vogue in various parts of the Netherlands. It is generally placed in front of a dike and not on it—so that the slope may be sodded, and the force of the waves so broken that the sod may suffer no detriment.

Stone, however, is the main resource, and in some situations it is the only one—for instance, where the effect of tidal scour is added to the

force of the winds, and the damage is not alone above water but also below, so that deep water is found at a very short distance from the foot of the dike, and continually encroaches upon it. Such a situation is found at the Helder, the extreme northern point of the main land of North Holland. A strong current flows through the strait between the Helder and the island of Texel, which, with the assistance of storms, has scoured and beaten away the bank until, at a distance of 40 meters from the toe of the dike at flood-tide, a depth of 25 to 28 meters was found in many places, and at 50 meters a depth of nearly 30 meters,* indicating a mean slope of about 1.5 to 1. The only remedy that was thought available was a rip-rapping of heavy stone, combined with hoofden where necessary. The former part of the design was effected by throwing in massive blocks of Norwegian granite, which lodged upon the slope and were renewed as fast as they were displaced by the waves and the currents, combined with their own gravity, until an equilibrium was at length reached.† Nevertheless, for a long time continual repairs were necessary, and careful soundings were made at close intervals, to determine the exact localities where deficiencies existed. It was estimated that 800 or 1 000 tons of stone were used annually for this purpose. The hoofden also seem to be entirely of stone, and if so must have consumed an immense quantity of material. They are not placed along the whole reach, but only in the most exposed spots. They are spaced at variable distances, which the author estimated at an average of about 100 meters, and have a seaward slope of about 40 to 1. They are not all of the same height above the sea level, those most exposed (the western) being the highest, and projecting some 3 feet above high water at the shore end, tapering thence to about high water grade at the seaward end. Going eastward each hoofd is a little lower than the preceding. Above water the stone are regularly laid, though in natural blocks, from 1 to 2.5 feet in diameter, and say 1.5 feet thick. They are laid on a foundation of *puin* or broken brick. The dike itself is not of uniform dimensions. The crown is about 30 feet, the back slope about 2.5 to 1, the front slope broken, convex, the upper part about 10 to 1, the lower part generally about 6 to 1, though sometimes the long slope is continued unbroken. (See Plate LV.)

Large and heavy brick, burned specially for the purpose, have been used instead of stone for revetting exposed fronts, but it is believed they

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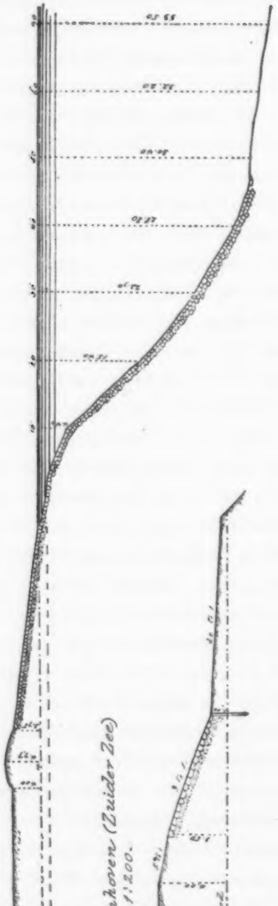
* Storm-Buysing, i, 377. † See Plate LV.

PLATE LV.
TRANS. AM. SOC. CIV. ENGS.
VOL. XXVI, NO. 534.
STARLING ON HOLLAND DIKES.



Section of the Helder-Dike (from Storm-Buysing.)

Dike near Vollenhoven (Zuider Zee)
Scale 1:200.

have not been found economical. The principal objection to stone pitchings is their great cost—and this has limited them to very important and exposed places. Where continuous stonework is used, brush is on longer necessary. A thin straw mat (*krammat*) is first laid—at least this is the practice in Zeeland. On this is placed a layer of brick, laid as closely as possible, and on the latter a layer of *puin*, or broken brick, 6 or 8 inches thick. This is followed by the stone itself, which has a thickness of 12 to 16 inches. At certain very exposed points still heavier work is used. The work begins at the bottom, with a row of strong wattling or of *perkoenpalen** placed about the low-water line. The smallest stones are placed at the bottom, as this part of the slope has the least of all to fear from the waves. The loose brick serve to correct inequalities in the depth of the pieces of stone, as they can be so adjusted as to bring the upper surfaces to a level. The stones are placed as closely and snugly as possible, the rows breaking joints, so that there shall be no continuous channels under them for the water. The pieces must each be firmly bedded in the loose brick, so that they shall not depend on one another for support. The revetment must project beyond the desired profile, and be rammed with wooden rammers to grade. Finally, all interstices are tightly filled with spalls or brickbats, and in some places even with shells.

For great sea dikes and other heavy work the stones are large and massive, and of those varieties which have the most specific gravity. For the lighter class of sea dikes and for river dikes the material which is of almost constant employment is *basalt*. This stone indeed plays a most important part in all river constructions in Holland and the Lower Rhine. The variety which is most frequently used is the well-known columnar basalt, familiar to us by descriptions of Staffa and the Giant's Causeway. It is brought from the Seven Mountains on the Rhine, or from that vicinity, and transported by boats, without breaking bulk and at very cheap rates, down the Lek, the Waal and even the Maas, via the several channels of communication between the last-named rivers. It is very easily quarried. It exists in immense cliffs, presenting a striated appearance from the columns of which they are composed. A

* *Perkoenpalen* are short sapling piles of oak or fir, 5 or 6 feet long and 4 or 5 inches thick. The term is untranslatable, as the Dutch engineers themselves do not know its derivation. They are of constant use in stone revetments, being placed at the bottom, or at intervals, in close rows, on the slopes, especially in steep slopes, to keep the stones from slipping downward.

very striking example of this formation constitutes a conspicuous feature of the scenery of the Rhine at Erpel, where the cliffs abut directly on the river. Vast quantities of the blocks may be seen loading on the beautifully modeled Rhine barges about Unkel, Remagen, and especially Linz, whither they are brought from quarries in the interior. The process of quarrying, it is stated, consists in merely wedging apart the vertical or inclined columns, when they fall of themselves, and break or are broken into suitable lengths. The Dutch Government, it is said, owns its quarries. As delivered for use, the blocks are hexagonal or pentagonal in section, 9 or 10 inches in diameter, and of such length as is demanded for the work, the price increasing greatly with the length. The price of blocks of ordinary size, delivered at Rotterdam, is about one dollar per ton, the rate varying, of course, according to season and circumstances.* The blocks are laid as closely and regularly as possible, their polygonal shape permitting very neat joints to be made without cutting. It has been maintained, but without good reason, that a steep stone pitching was better than a flat. A slope of 6 to 1, if the stone be good and heavy, is sufficient for the worst cases. Some parts of the Helder revetment, however, have a slope of 10 to 1. The very unfavorable situation of this dike and its great importance justify extraordinary precautions.

In Zeeland stone facings are themselves sometimes beset with *perkoenpalen* or palisades, which project 0.8 meter above the stone, and are placed, not close together, but with an interval between them. Sometimes all the rows run in the direction of the dike, sometimes also perpendicular to it, so as to form squares or pens. These compartments have two objects: first, to break the force of the waves without turning them back; second, to prevent any defect in the stone-covering from extending too far. Formerly this kind of work, called *staketwerk* (stockade or palisade work) was very common in Zeeland. Now it is confined to a few very dangerous points.† The most dangerous of these and one of the most notable in all the Netherlands is the famous Westkapelle dike on the western shore of the island of Walcheren. This and the equally famous Petten and Hondsbosch dike on the western coast of Holland are embankments of sand, designed to fill gaps in the line of dunes which mostly defends the shores bordering on the North Sea with gigantic natural mounds, generally far superior in height and strength

* Mr. Leemans. † Storm-Buysing, i, 394.

to any artificial banks. At some points, however, the dunes are very thin, and are becoming thinner from the onslaughts of the sea and the winds, and at two places they are missing altogether, namely, at the localities just specified. The gaps have been closed by enormous works, very similar to one another. The Petten and Hondsbosch dikes were not seen; but a special visit was made to the Westkapelle dike, and the author had opportunities of seeing, not only the work itself, but the manner in which the sea defenses were constructed, for they were repairing and extending the hoofden, and work was seen in all stages of forwardness.

The exposed part of the coast of Walcheren begins several miles north of Westkapelle, at the little unpretending sea-side resort—not yet quite a watering-place—called Domburg. This quarter of the island has to endure the full force of the north winds of the German Ocean, with a sweep that is unbroken by any land for 2 000 miles. At Domburg the encroachments of the sea have been so extensive that they are about to build a dike there, to "back up" the streak of dunes that has already become too thin for safety, while the further inroads of the waves are prevented by strong stone revetments and a formidable series of hoofden, extending, it was said (for the whole line could not be followed), all the way to Westkapelle. The front slopes of the dunes are planted with dune grass or *helm*, that they may not be blown away by the wind.

The dunes are justly regarded as of such value that extraordinary pains are taken to preserve them. Where there is a high beach, extending as far as the ordinary flood line, this of itself will protect the sand hills from everything except very high tides. Where the beach is not sufficiently high, sometimes efforts are made to raise it artificially by means of brush or reed screens, which will collect the loose sand as it is blown about by the winds, and cause it to lodge under their lee, until the screens themselves are buried. So soon as this occurs, new screens are built, intermediate between the former and extending further out. Sometimes, by this cheap means, considerable territory is gained, and if it be possible even to keep pace with the annual loss, it is so much gained at small cost. If such a device is insufficient the dunes must be treated like exposed dikes, and protected either directly by revetment or indirectly by hoofden, or both. The dunes are protected by the former method by first reducing the front to a regular and somewhat long slope,

covering it with a thick pitching of clay, and then applying the straw mat, brick rubble and stone, or other suitable dressing.

There is a kind of clay found in Zeeland, and perhaps elsewhere in the Netherlands, which is very proper for such purposes. It is called *leem*. It is stiff, waxy and tenacious, and becomes very hard when dry; for which reasons it is not well suited for tillage. It lies in strata from 3 to 6 feet in thickness. The dike administration or the contractor buys it of the proprietor at so much per cubic meter (about one florin is a common price), and, so to speak, quarries it, cutting it out by the spade in regular cubes of 6 inches or so. The blocks are laid in courses on the slope of the dike, and closely pressed together by the feet of the laborers.* The usual thickness of the clay pitching is 1 meter. The same method appears to be practiced elsewhere, in facing the slopes of the canals and river dikes.

The Westkapelle dike attains a height of 5.5 meters above high water or 8 meters above low water. Its dimensions are shown on the accompanying cross-section, given by the resident engineer, Mr. Koole.† It will be seen that the water slope is broken into several sections, the lowest 22 meters in horizontal length, standing at 6 to 1, the next 9 meters, at 7 to 1, the next 6 meters, at 8 to 1, the next 59.7 meters, at about 17 to 1. At the foot of the lowermost slope is a row of heavy *perkoenpalen*, and beyond this is a bestorting or rip-rap, extending about 20 meters. The slopes are dressed, first with *leem*, 1 meter thick, then with a straw mat, as usual, and stone. The lower slope is faced with basalt, the next with Doornik stone (Doornik is the Flemish designation of the city which we generally call by its French name, Tournai), and the third with basalt again, the fourth with straw mat, basalt, and finally sod, in turn. The stone pitching is from 0.3 to 0.4 meter thick. The rip-rap beyond the foot is composed of very heavy blocks, none being received that weighed less than 300 kilograms. Smaller pieces were tried, but they were thrown up by the waves. A short distance above the low-water line begins the *staketwerk* or stockading, which is a conspicuous feature of the Westkapelle seawork. This consists of eight longitudinal rows of small piles, about 8 inches thick and 10 feet long, projecting about 4 feet above the stone. They are placed pretty close

* Verbal statement of Mr. Bourdrez, a native and resident of Middelburg, in the Island of Walcheren. This intelligent young gentleman was kind enough to accompany the author on his trip about the island, and gave him much valuable information.

† See Plate LVI, Figure 1.

together in the rows—less than their own diameter apart—and are fastened together by a strong waling-piece. The rows are about 9 feet apart, and are connected by stout horizontal braces at intervals of 8 feet or so. Spaces are left occasionally in the rows for purposes of inspection and repair, which spaces are not opposite to one another, but placed diagonally, so that an aisle or gangway is thereby formed, extending all the way through the eight rows, at an oblique angle.

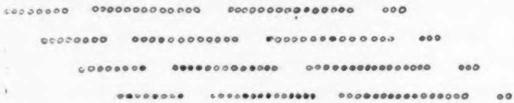


FIG. 4.

The straw mat is mostly composed of dried reed or swamp grass, which is used, for economy's sake, when it is practicable. Mr. Koole said that it answered very well in the situation where it is placed, namely, on the long, flat, upper slope, where no waves reach it, merely the swash. Elsewhere the author was told that it was not efficient against heavy storms.

The hoofden at Westkapelle and along the coast, pretty much all the way from Domburg, are elaborate structures, built with much care, as they may well be, for they have to suffer tremendous shocks. They consist of from two to four rows of piles, projecting 6 feet or so, driven about 6 or 8 inches apart in the row, very much like the stockade work on the slope of the dike. Between and on each side of the rows is a carefully laid bed of clay, brush and stone (Doornik), the stone being about 2 feet square and of tolerably regular shape. The slope of the hoofden seaward is from 23 to 35 to 1—a broken slope, the steeper part being next the shore. The rows are strengthened by waling-pieces on both sides, and the hoofd is divided into sections cribwise by cross-piles and heavy horizontal ties. A plan and sections of one of them is given. (See Plate LVI, Figs. 2 and 3, and Plate LVII.) The piles of which it is composed are from 12 to 18 feet long, the shorter pieces being set near the shore. They are about 8 inches in diameter, are of pine or some similar wood, and of those that were seen some were creosoted and some were not. They are driven to a little less than half their depth, the seaward piles being driven the deepest. The instrument with which they were driven was a hand pile-driver with one lead, such

as is sometimes used for sheet piling, the hammer being furnished with two square collars, which clasped the lead, thus:

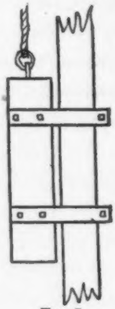


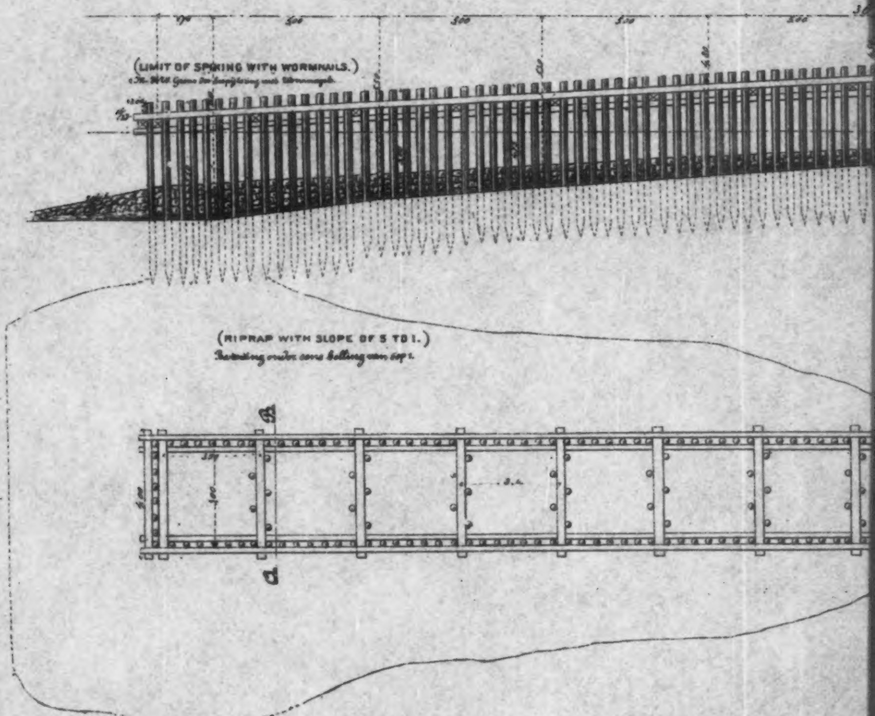
FIG. 5.

It was worked by eight or ten men. Being asked as to the importance of the part which the hoofden play in the defense of the dike, Mr. Koole said that they were of the greatest service, and were, in fact, indispensable against the formidable north winds—that, wherever they were missing, the work had suffered serious damage. They are placed at various intervals, the furthest apart being, as it appeared to me, about 300 meters. They are of various lengths, according to the exposure and the interval between them. At the Westkapelle dike itself they are short and close together, owing, probably, to the depth of the water, which is considerable at that place and forbids the hoofden to be made very long. Their standard length was understood to be 120 meters. There is a mattress, 40 meters long, at the end of each hoofd. It will be observed that both pilework and stonework are much heavier and stronger at the seaward end, and that the rip-rap about the sides of the spur increases as it progresses in that direction. The piles are studded with "worm nails," that is, nails with broad, flat heads, as a protection against the teredo, to a distance of 2 meters below high tide, that being about the upward limit of the range of the destructive insect.

Mr. Koole said that the seas often reached entirely up the outer slope, and occasionally a little of the swash ran over the crown. The great dike is 3 800 meters long, or about 2½ miles. Its crown is, perhaps, 20 feet above the natural surface of the ground. The whole of this enormous work, with the long line of hoofden, was built and is maintained by the single small island of Walcheren, which, so far as the dike administration is concerned, constitutes a polder to itself. As the dike is not essential to the safety of the rest of the kingdom, the general government contributes nothing. The island contains only 17 990 hectares, or about 69½ square miles. The dike tax is something over 200 000 florins annually, or about $80 000—being at the rate of about $1.80 per acre. The tax is not imposed according to acreage, however, but according to value. It is strictly a land tax.*

Similar in construction are the Petten and Hondsbosch hoofden and the Delfland hoofden. From the number and almost exclusive use of

* Mr. Bourdrez.



(LIMIT OF SPIKING WITH WORMNAILS.)
(RIPRAP WITH SLOPE OF 5 TO 1.)
1 ON 17

PAALHOOFD.

(PILE DIKE)

PLATE LVI.

Zijaanzicht.

(SIDE VIEW)

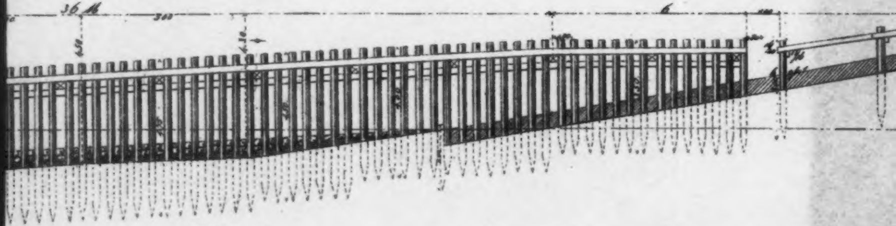


FIG. 3.

(GROUND PLAN.)

Plattegrond.

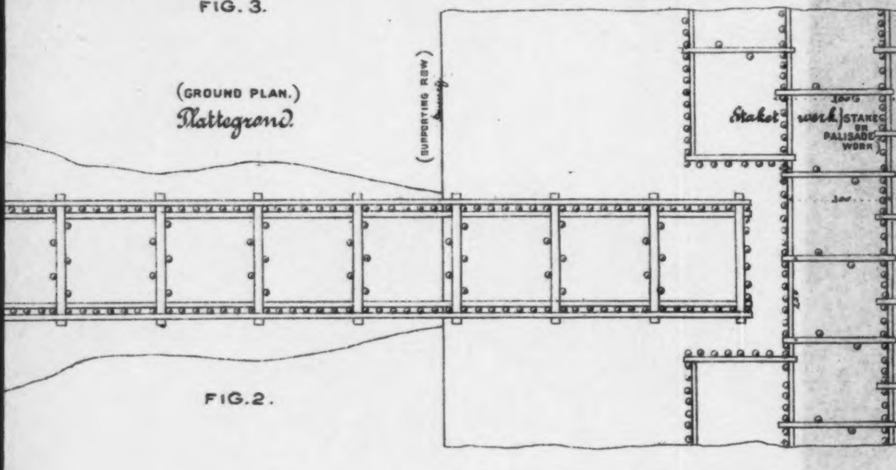


FIG. 2.

Profiel bij dijkpaal 10.
Schaal 1/200

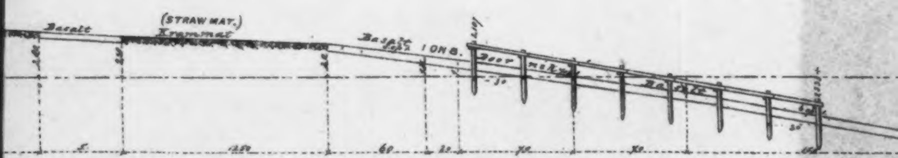


FIG. 1.

PLATE LVI
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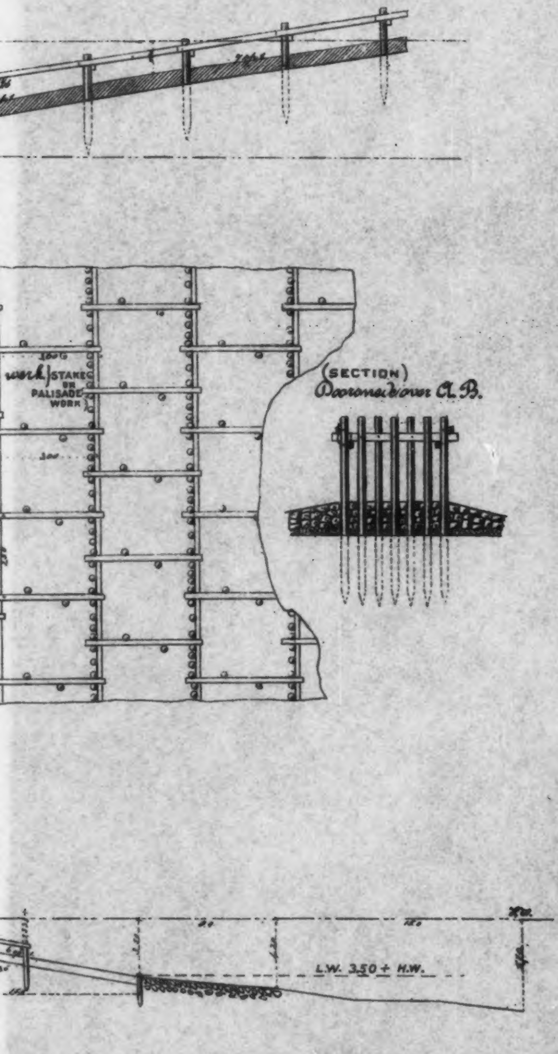
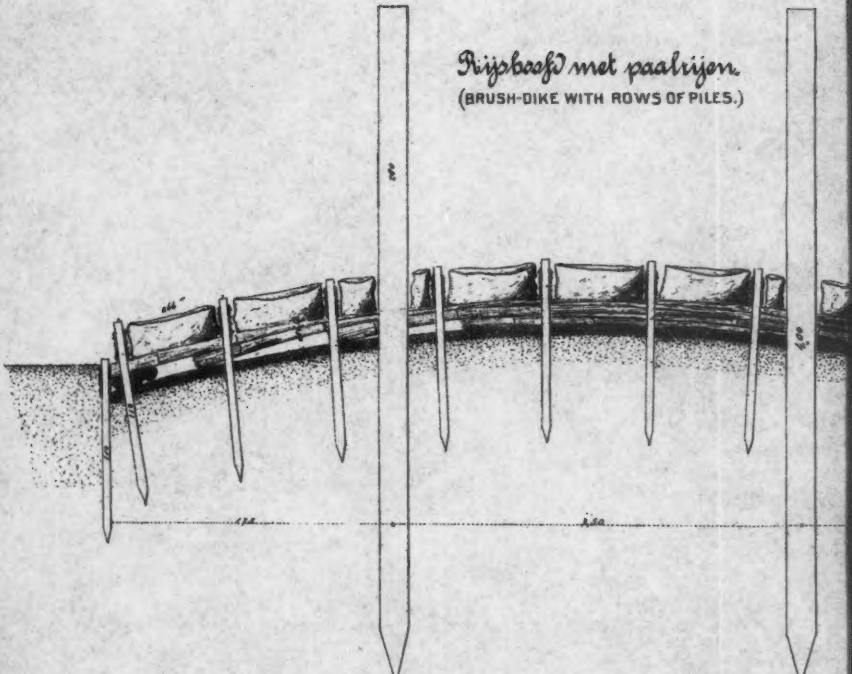
STARLING ON HOLLAND DIKES.



Rijsboofd met paalrijen.
(BRUSH-DIKE WITH ROWS OF PILES.)



Rijshoofd met paalrijen.

(BRUSH-DIKE WITH ROWS OF PILES.)

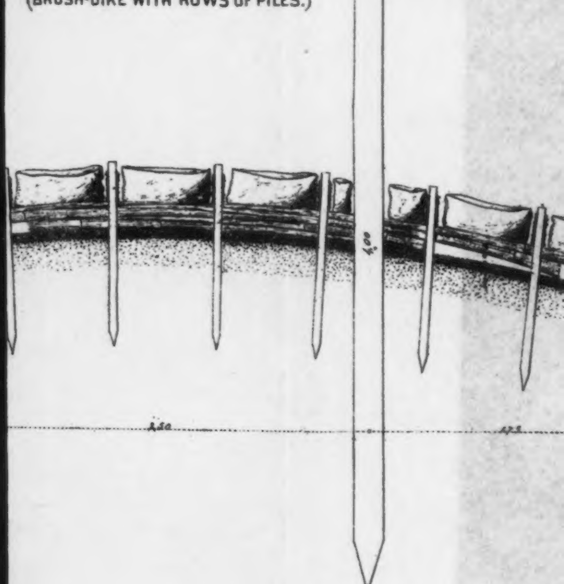


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PLATE LVII.
TRANS.AM.SOC.CIV.ENG'RS.
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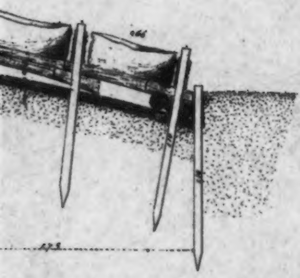
STARLING ON HOLLAND DIKES.



these works, it may be inferred that they fulfill their purpose, and that in very exposed situations no equally effective means have been devised. These elaborate stone and pile works are very expensive, and it must not be forgotten that there are other contrivances which may be sufficient in less critical and less important situations. The materials which may be made to answer in place of those just named are mostly straw and brush.

The straw mat or *krammat* (literally cramp mat) has been mentioned more than once. It is a peculiar and important feature of Dutch construction. Minute directions for making it are contained in the textbooks and in the general regulations. It originated in Zeeland, as did many useful contrivances which are now common to the whole kingdom, being evolved, doubtless, out of necessity by those independent and hardy islanders, whose whole life has been, more than that of any province of Holland, a fight with the sea. It consists of a thin layer of carefully selected straw, disentangled and laid straight, parallel and close, cramped by ties or binders of the same material, placed at short intervals, and pressed into the earth by a two-pronged spud or fork. When designed as a foundation for other work it is only about three-quarters of an inch thick. Its office, in such constructions, is to keep the brick, etc., from sinking deeply and irregularly into the new earth, which is yet green and imperfectly compacted, and has not suffered its normal shrinkage. After a while the krammat decays, but then the slopes are firm, dry and hard, and fit to support the stone facing.

A straw mat is also frequently employed to protect the slopes of new work where the sod is deficient, or where it has not had time to grow properly, or where sod alone is considered an insufficient protection. For this purpose the straw is placed in layers of at most an inch thick, the stalks being perpendicular to the direction of the dike. Rye straw is generally preferred, as being longer and tougher, though wheat, barley and oat straw may be used, and also (in part) dry or green reed or swamp grass. Straw, in its technical sense, means straw as it comes from the process of threshing, long, short or tangled, and, perhaps, with weeds in it. From this is separated a finer product called *glui*, which is prepared by combing or carding the rough material with a wooden comb, thus cleansing it of defective stalks and weeds, and laying it straight and even. It is then made into bundles. It is glui that is principally used for mats. The work is begun by laying a thin but

close layer of straw, half the thickness of the proposed covering, and upon it another layer of wheat or rye glui, or green or dry reeds, the green being used below ordinary flood height and the dry above that point. On new ground, suitable for sodding, straw alone is used (no reeds). The thickness of the whole mat, after cramping, is from 0.6 to 1 inch. The cramping is done as was previously described. As laid by expert Dutch workmen, the krammat is a beautiful and very close covering—so close as to be an efficient protection for new slopes against rains, or even moderate waves. It lasts only a year, and must sometimes be renewed before that time. In any event, it is taken up in the spring of the ensuing year, and if necessary afterward replaced by another.

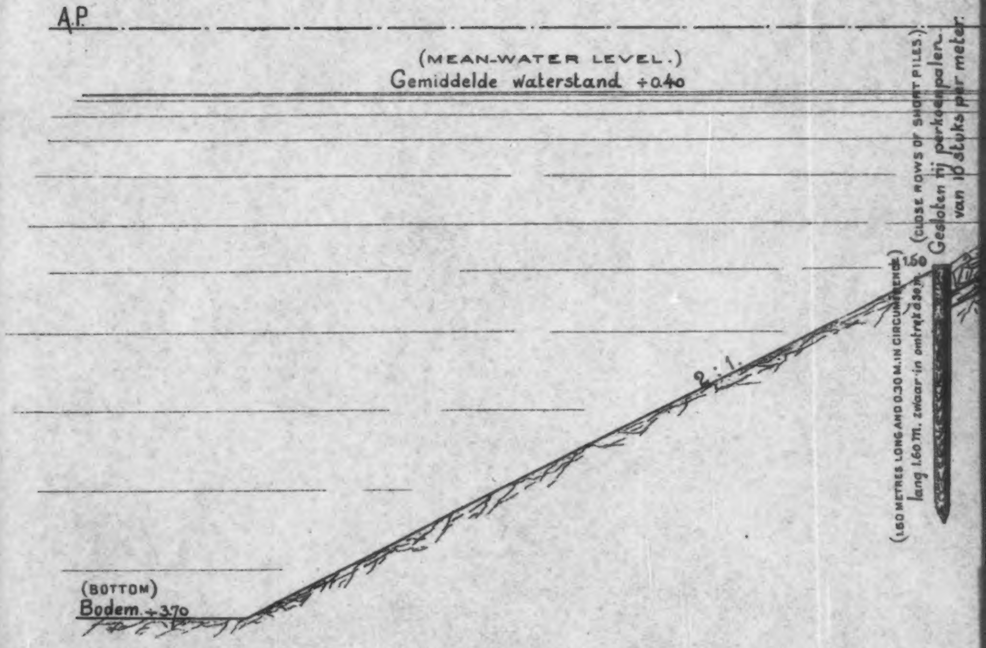
To make a brush dressing, or *rysbeslag*, a thin straw mat is first laid, and upon it a thick layer of reed, 5 inches or so in depth. The latter layer is placed perpendicular to the first, that is, parallel to the direction of the dike. The brush, in bundles, is held perpendicular to the reed, and is then fastened down by a wattling of tough and long twigs, carefully and firmly woven between stout stakes, and laid down for greater security by anchoring stakes with forks pointing downward, or having pins driven through them. Sometimes the brush is maintained in position by timbers confined by stakes with iron hooks or bolts driven into them. On the upper rivers, where the danger from winds is less serious, the straw mat is often omitted, and the brush sometimes laid, not in bundles, but broadcast over the slope of the dike. The work is begun at the top of the slope and the points or tops are placed upward. However, there are various ways of making brush dressings. The brush covering is frequently weighted by stone—the wattling being then omitted, and only stakes used, driven closely together in rows. This method is more than twice as expensive as the other, but it also lasts twice as long (six or seven years, as against three). The embankment across the strait called *De Geule*, which used to connect the Eastern and Western Schelde, is protected in this way.*

The brush so frequently mentioned is not a wild growth, as in America. The so-called *ryshout* is an artificial product, raised for the market, and delivered in merchantable form. As it comes to the market it is mostly osier or willow brush of three or four years' growth,

* For slopes which are not much exposed, as for the side-walls of canals, a covering of brick rubble alone is sometimes used, kept in place by parallel rows of light stakes, with a row of strong perkoenpalen at the bottom. See Plate LVIII, which shows the method of protecting the banks of the Merwede Canal.

Oeververdediging langs het Mer

(BANK PROTECTION ALONG THE MERW



rverdediging langs het Merwede-kanaal.
NK PROTECTION ALONG THE MERWEDE CANAL.)

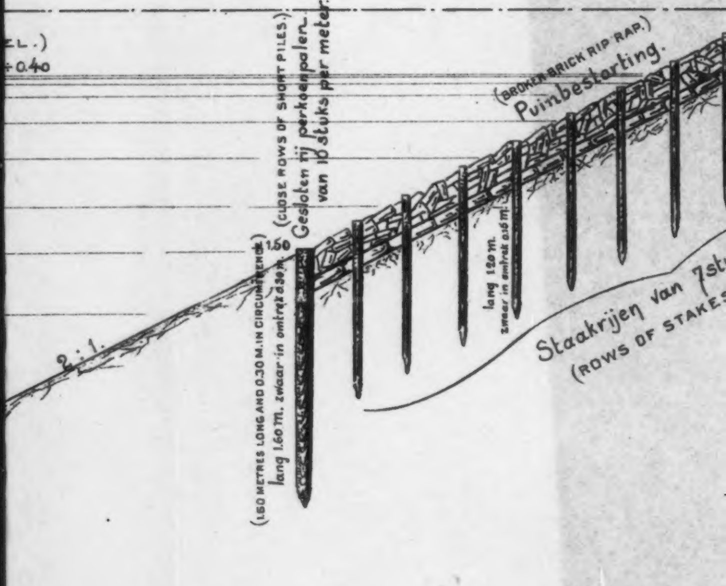


PLATE LVIII
TRANS.AM.SOC.CIV.ENGRS.
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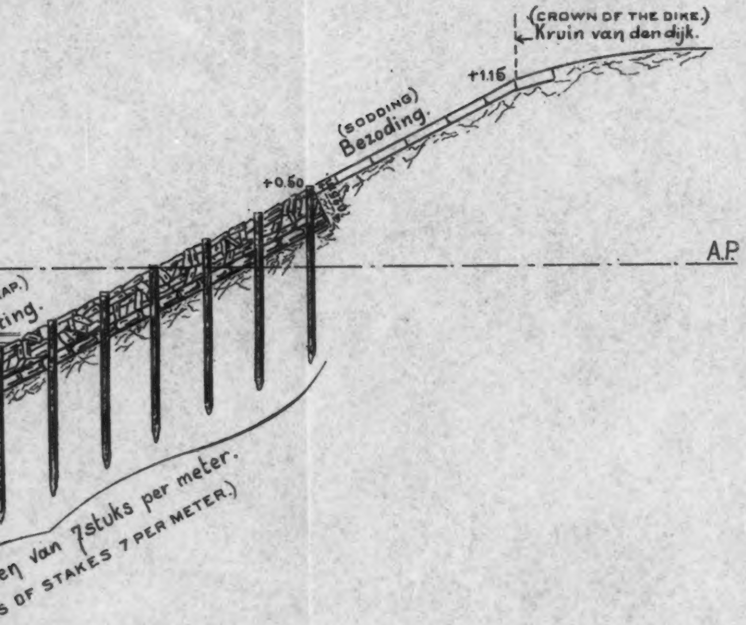
STARLING ON HOLLAND DIKES.



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though sometimes oak of eight years is used, and occasionally other kinds of wood. It is required to be cut between the 1st of October and the 15th of March, while the sap is out of the wood and the bark more adhesive. It is delivered in small bundles of various sizes, according to classification, the requirements for each kind being minutely defined. The growing of this brush is an important industry in many parts of Holland. In the Tielerwaard, Alblasserwaard and elsewhere the author saw immense plantations of pollard willows and also of young trees planted mostly in rows, sometimes with pasture or grain land between. Frequently wet and low spots were thus utilized. The principal sources of this product are the districts bordering on the Lek and the Waal, the marshy part of Friesland, certain islands of Zeeland, Brabant and Gelderland. Each of these varieties of brush has its distinct characteristics. Holland brush is of willow, either pollard or sapling, or osiers grown on the foreshores, between the dike and the river. The latter kind must be at least three, the former of four years' growth. Schouw (Zeeland) brush is of five to seven years' alder, willow or birch. Gelderland or Limburg brush is five years' alder or fir, three years' willow, or eight years' oak. The Brabant product consists mostly of oak, ash, birch, hazel, etc., of five years' growth. Gaasterland brush (Friesland) is of birch.* These varieties are subdivided into different sizes and qualities according to the purposes for which they are to be used. Brush is employed in a hundred ingenious ways in Holland, and in vast quantities. It is used for baskets, for gabions for military work, for fences, for dike protection in time of high water, for retaining in place rip-rap which protects canal slopes, etc., for foundations to spurs for silt catching and the like, and for the greater spurs or hoofden which play such an important part in seaworks, as well as for mattresses and fascine work of all kinds. It is also used, it is believed, for small fuel. It is met with everywhere, stacked on the crown and slopes of the dikes for high-water use, or at the landings ready to be loaded on barges for river-improvement work. As there are no primitive forests left in Holland, the rough-and-ready methods of construction which prevail in America, where the wild and natural growths are common and cheap, cannot find place in the older country. Instead of trees, poles and large brush, which would be of long growth and dear, the Dutch use combinations of small brush, which can readily be raised artificially and in a short time.

* Algemeene Voorschriften, pp. 184–7.

Damages to dikes must be speedily repaired, or they will lead certainly to increased trouble and cost, perhaps to actual calamity. If the sodding be injured and the slope badly washed, the damaged spots must be leveled off by paring away the irregularities, at least the sharp projections, and covering the place with a straw mat or a dressing of reeds or brush. The actual filling of the gaps or holes is not recommended, as it is difficult, during the winter season, to bring about a thorough union of the new earth with the old, still more difficult to secure a good and firm sod. The least storm will wash away the new work. It is best therefore to use palliative measures only during the time of high water, and to put off the complete restoration of the slope to a later season.* When the damaged work has been covered with a straw mat the gaps should also be repaired with a straw mat, without previously filling with new earth. Brush dressing is used by preference in those places which were previously protected by brush, or where injuries would be of great consequence and a straw mat alone would be insufficient. Especially is brush to be recommended where the earth is so badly eroded that paring away without filling would not make a slope suitable for the reception of a straw mat; because the brush, by a tight and strong wattling, can be made to stand at a much steeper slope, and is much better for the protection of the new earth, if such must be used. The greater costliness of the brush dressings is offset by the fact that most of the material can be saved and used again.

If the outer slope be so far cut away by the storm as to encroach upon the crown, as often happens, it becomes difficult to restore the slope so that a brush dressing will stand, without a filling in of some kind. Then fascine work may be resorted to, or a facing of stakes, timbers or beams, backed by planking or hurdles,† as either of these materials may be at hand, or can be got most cheaply or readily. The foot of such a structure requires protection against wash. For this purpose, the bottom plank of the revetment may be set from 8 to 12 inches in the ground, or short upright planks may be driven to cover the foot. A layer of brush or straw may be placed next the foot of the work, if preferred, of a breadth of 6 or 8 feet. If the slope be covered with stone, and some of them be displaced, they must be restored to their position as soon as the storm

* Storm-Buysing, Waterbouwkunde, i, 399.

† Hurdles are defined to be flat wickerwork pieces of irregular sizes, rectangular in form, from 2 to 4 feet wide and from 6 to 8 feet long. It is thought they are not much used nowadays.

permits, or if the injury be great and the soil badly cut, the stone and brick rubble must be cleared away altogether and replaced by a stout brush dressing.

One of the most convenient and efficient means of protection is afforded by tarpaulins, weighted so as to cover the injured slopes. They cannot be used, however, where there are already stone or brush coverings, as they are soon destroyed by the projecting stakes or sharp angles. In Friesland and Overyssel, where the dikes are mostly well protected by grass, tarpaulins are stored in the dike magazines, and have often saved the dikes from breaking. These magazines are essential features of the dike administration throughout the Netherlands. They are placed at intervals of several miles, and contain the implements and materials most likely to be required for high-water use,* namely, wooden mauls of different sizes, iron hammers, sledges, post-hole diggers, rammers, crowbars, axes, picks, mattocks, saws, augers, wheelbarrows, lanterns, torches, &c.; brush, stakes, timbers, plank, spikes, hurdles. The plank, stakes and spikes are principally intended to raise or "top" the dikes, in case of necessity, by an *opkisting*, that is, a kind of small temporary coffer-dam of planks set on edge and filled in with earth. The uses of the brush are manifold, and some of them have been indicated. It seems especially much used on the river dikes, which are generally protected only by grass. After high water it is taken up again and stacked in bundles on the dikes.

One of the most alarming and serious accidents which can happen to a dike is a sudden sinking or collapse, caused by the undermining of the bank below the water-line. These slips are not at all the result of storms, but of the steady action of the current, and happen frequently in time of dead calm. The treatment of such a case depends on the nature of the injury and the extent of the danger. In general, the first thing to be done is to build up the bank under water by a close but light brushwork, in order to prevent further sliding. If the damage is not extensive, this work may be carried on until the outer slope is rebuilt. The brushwork, which is laid in tiers, in bundles,† is covered with cubes of clay taken from the foreshore, which weight it, and assist in protecting the sand strata of the bank. If the injury, however, extend to the inner slope, it will probably be necessary to build a new dike inside of

* Storm-Buysing, ii, 58-9.

† There is a special kind of brushwork called *baardwerk* or *bleeswerk*, which is adapted to this purpose.

the old one. Interior dikes are sometimes built, to give additional protection to very important and very exposed points, as in the case of the Petten and Hondsbosch dike, which is of sand. There is a *slaperdyk* or interior dike here, which would at least protect the country south of that great work, should it yield to the sea.

Should breaks unfortunately occur, they must be closed as soon as the state of the water will permit. In the case of rivers, there is usually no difficulty, provided we wait until the flood is past. Where the gap is in a sea dike, however, the task may be a very serious one, from the constant in-and-outflow of the tides. This is sometimes specially embarrassing if the channel through which the tide flows be too narrow to fill the internal basin till the end of the flood—for then there is no slack water at all, but a continual current one way or the other, which is often so strong as almost to preclude work. It is frequently necessary, in such cases, to enlarge the channel. Again, if the current through the break be very strong and the basin very large, the capacity of the latter may be diminished by diking off a portion of it. Such a process may be repeated two or three times, as happened at the closure of the Dokkumer Diep, in Friesland, in 1729. It is evident that earth alone will not suffice for a dam in such cases, for it will be washed away as fast as it is put down. Some more coherent material must be used, as a foundation at least, to hold the earth in place. The body of the dike may be composed of earth, inclosed between a mattress of some sort on the bottom and *zinkstukken* in layers on the sides, as in the case of the Schellingwoude dam, hereafter to be mentioned.

The dangers of disaster to the river dikes of the Netherlands, though not peculiar to that country, are yet not exactly the same as threaten the levees of the Mississippi. The source of greatest peril to the lands bordering on the branches of the Rhine is the gorging of ice in the shallows and bends—an incident unknown to the great American river in its alluvial part. On the other hand, the most serious cause of alarm to the dwellers in the Mississippi Valley is the long duration of the high stages—a phenomenon which seldom or never occurs in the rivers of Holland. Danger of inundation may arise, say the Dutch engineers,*

* Beekman, Nederland als Polderland, p. 42. Id. De Strijd om het Bestaan, p. 34. Storm-Buysing, ii, 30-31. Mr. Beekman was formerly an officer of engineers, and is now a professor in the Gymnasium at Zutphen. His works, which are very recent and mostly of a non-technical nature, are very popular, and have done much to diffuse a knowledge of the dike and water system of Holland among the Dutch themselves.

first, in open water, that is, when there is no heavy ice running; and second, in the opposite event, through engorgement or jamming of masses of the said ice. Breaks in the former case are very rare. When they do occur, it is mostly from sinking or giving way of the dike or its foundation, and this through four causes:

First.—Undermining, in the case of a sheer dike, that is, one without a foreshore, by the direct action of the current. The means of meeting this danger have already been described.

Second.—Leakage through or under the dike. If through the dike, it may occur through the imperfect compacting of the layers of earth which compose the dike, or for other reasons. It is often very manifest to the eye, being revealed by moist spots on the inner slope, and sometimes by springs or wells lower down. Sometimes the sources of these springs are situated high up on the outer slope—sometimes very low—wherefore they "work," as the Dutch express it, at very variable stages. The sinkings occur frequently at the highest water, but often, also, singular as it may appear, on a falling river. This strange phenomenon may be explained by supposing that the opening on the outside is high up, and ceases to operate at lower stages. The hole through the dike is then filled with water at flood-time, and a constant though slow current passes through it, gradually scouring out the sandy material, if such there be, through which it passes. Thus a cavity is formed, the sides of which are sustained by the pressure of the water as long as it is full. When the river falls, however, the supply from the source is cut off, the cavity emptied, and its walls consequently collapse, causing a tumbling in of the loose material, and eventually a sinking in of the crown or slope of the dike. The same cause may operate under instead of in the body of the dike, producing then cavities in the foundation or underground. These holes do not at first give any trouble, while they are small and are easily upheld by the pressure of the internal water. It may require a series of years and a number of small collapses to bring the cavities to such a size that their falling in will cause a similar sinking on the part of the hard outer crust.

Third.—Through the weakness of the foundation. The pressure of the water increases until the loose and porous underground can no longer stand it and gives way laterally, when, of course, a sinking or even the total destruction of the superstructure will result. In such an event the dike is said to stand on bad soil (*op slecht staal rusten*). The

important Lek-dikes are in this predicament. So is the New South Linge dike. A sinking may also result from the mere softness or compressibility of the underground. These accidents generally occur in the course of construction, and the greater part of the settling manifests itself before the completion of the work. Very frequently, however, the advent of the spring flood is the signal for further sinking—the underground, which may have partially dried out, being again infiltrated with water, and consequently softened.

Fourth.—Through actual overflow over low places. If once water be permitted to run over a dike, if the material be at all sandy (as it frequently is, on the back slope at least), it begins at once to cut gullies, which rapidly increase in depth and width. The overpour immediately begins to tell on the back slope, which is speedily scoured into holes, till large fragments fall in, and a break is the result.

The most formidable danger is from ice gorges. Unlike most of the rivers of the United States, the Rhine flows from south to north, and the coldest climate which it encounters is at its mouth. Hence the thaw sets in first at the upper part of its course and sets free vast quantities of floating ice, which, meeting the colder weather in the lower reaches, wedges itself into fast and thick ice dams, which form a serious obstacle to the flow of the rapidly increasing waters from above—and this all the more that such gorges frequently, or generally, are found in shallow places, where the river has been silted up. Hence results a rise of the flood waters which has no other limit than the breaking of the gorge or the overflow or destruction of the dikes. To obviate this, it has long been the custom to make the dikes a certain distance higher than the greatest flood waters free from ice. This distance was, in the case of the most important dikes, 1 meter; and that grade has now been increased still further to 1 meter above high water, ice gorges included. This will probably render unnecessary the device that has often been adopted, as has already been noted, of raising the dike by a temporary topping.

It may be interesting to note the difference between these conditions and those which prevail on the Mississippi, as induced by the difference of regimen of the two rivers. The Rhine rises in Switzerland, passes through Lake Constance, and when it leaves Basle is still a mountain stream, whose width is between 500 and 600 feet, and whose average depth, according to Baedeker, is from 3 to 12 feet. From Basle to Em-

merich, a few miles before it reaches Holland, according to the same authority, is 436.5 miles, and from Emmerich to the North Sea, at Brielle, only 101 miles more. The floods of the Rhine proceed mostly from the rains, snows and glaciers of the Alps, and have the characteristic features of their mountain origin; that is, they are short and sharp. They are somewhat modified by passing through Lake Constance, which acts as a regulating reservoir, making their duration a little longer and their height not quite so great. Even then they are up and down in a few days. The time during which they stand within 2 feet, for instance, of the top of the flood, is seldom more than ten days,* even at the lower parts of their course, as Schoonhoven or Gorinchem, and still less higher up. The author has before him the hydrographs of the principal rivers for several years,† from which is selected the hydrograph of the Lek for 1888,‡ as presenting the greatest flood during that period—which, however, falls some 4 feet below extreme high water. Contrast this with the accompanying hydrograph of the Mississippi for 1890,‡ when the river stood at a stage of more than 41 feet on the gauge at Greenville, 581 miles from the mouth (43.45 being the highest), from the 7th of February to the 27th of April—seventy-nine days. In 1891 the Greenville gauge read 42 feet or more (43.25 being the highest), from the 17th of March to the 29th of April—forty-three days. The levees of the Mississippi are fully as high as those of the Lek and the Waal,‖ and some portions are much higher. It is evident that the great duration of the floods of the Mississippi affords an additional and very serious element of danger. It is true that well-constructed and water-tight earthen embankments, of the best material, ought to resist hydrostatic pressure indefinitely; but perfection of construction is never attained in river dikes, for reasons already given. The dangers above adverted to, of the formation of cavities within or under the body of the dike by reason of infiltration and percolation, and of the absolute giving way of the stratum (if weak) on which the dike rests, are greatly magnified when the time of trial is increased fourfold or tenfold. If there be any weak spots in the embankment, its enemy, the water, will find them out, and the more certainly the longer and more trying the exposure. If the dike be unsound in

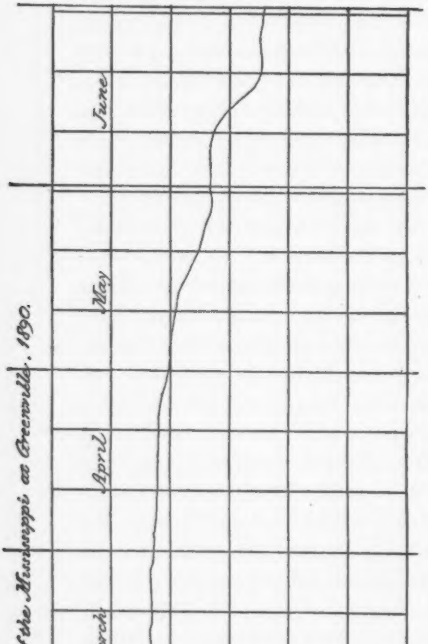
* Mr. Leemans.

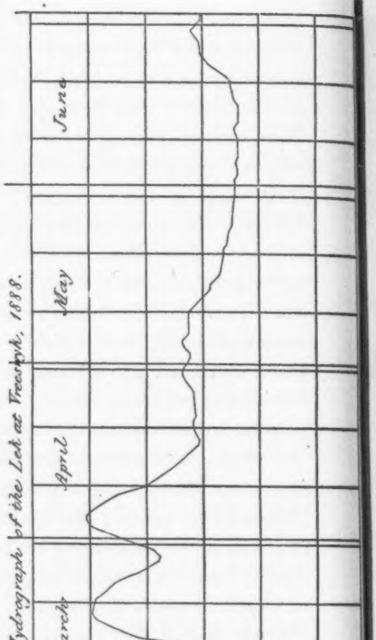
† Through the kindness of Mr. H. E. Bruyn, of the Waterstaat Office.

‡ See Plate LIX. It must be remembered that the two gauges are on different scales—one of meters, the other of feet.

‖ About 11 feet, it is supposed, is a fair average for each. In the Mississippi Levee District (on the left bank of the Mississippi) it is almost exactly 11 feet.

PLATE LIX.
TRANS. AM. SOC. CIV. ENGS.
VOL. XXVI, NO. 534.
STARLING ON HOLLAND DIKES.





any place, the defect may show itself in a leak or "well" on the inside, or it may remain latent until the last moment, and then result in a slough, a sinking or an absolute break, without warning.

Experience confirms this reasoning. The engineers and riparian dwellers of the Mississippi Valley do not so much dread a sharp and short flood as a prolonged one. As the people say, "the levees get rotten," and the foundations still more so. After several weeks of high water, it is found that in places, and sometimes for miles, the natural surface on the land side of the levee becomes so soft that it will not bear the weight of a horse or of a vehicle, and a sharp rod may be thrust into the ground for 8 or 10 feet or more. Even in the body of the levee such spots sometimes are met with, though they are not now so frequent as they once were. These places are always regarded with alarm by the people, though they are not uniformly or generally precursors of disaster—being formidable or not, according to the head of water against them, the dimensions of the bank and the nature of the soil. In point of fact, disasters have been more common where the ground near the base has been comparatively dry. Nevertheless, the soft spots are always given attention, the remedy applied being usually a banquette, resting on a layer of brush, to prevent sinking and the contamination of the new earth by the leak water.

The cavities developed in a levee by gradual and prolonged scour through sandy material are occasionally met with in the Mississippi levees and are popularly called "cisterns." They are not common, at least so far as discovered, being generally found out only by accident. Disasters of unknown origin have frequently been attributed to this cause, but for the most part on very imperfect evidence of the negative kind, that is, there was no other way of accounting for the break. Very frequently alarming holes break out on the land side, throwing out large quantities of sand—several cubic yards perhaps—which distributes itself in the shape of a regular conical crater. After the first outburst, the discharge of sand generally ceases, or becomes imperceptible, the hole still pouring out considerable volumes of water. The conduit, when sounded, is found to be vertical for a considerable depth. It is evident that the sand which was discharged has left a cavity somewhere, but probably pretty deep under the surface. These holes are always

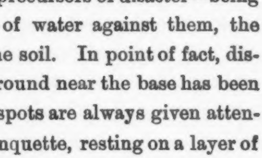


FIG. 6.

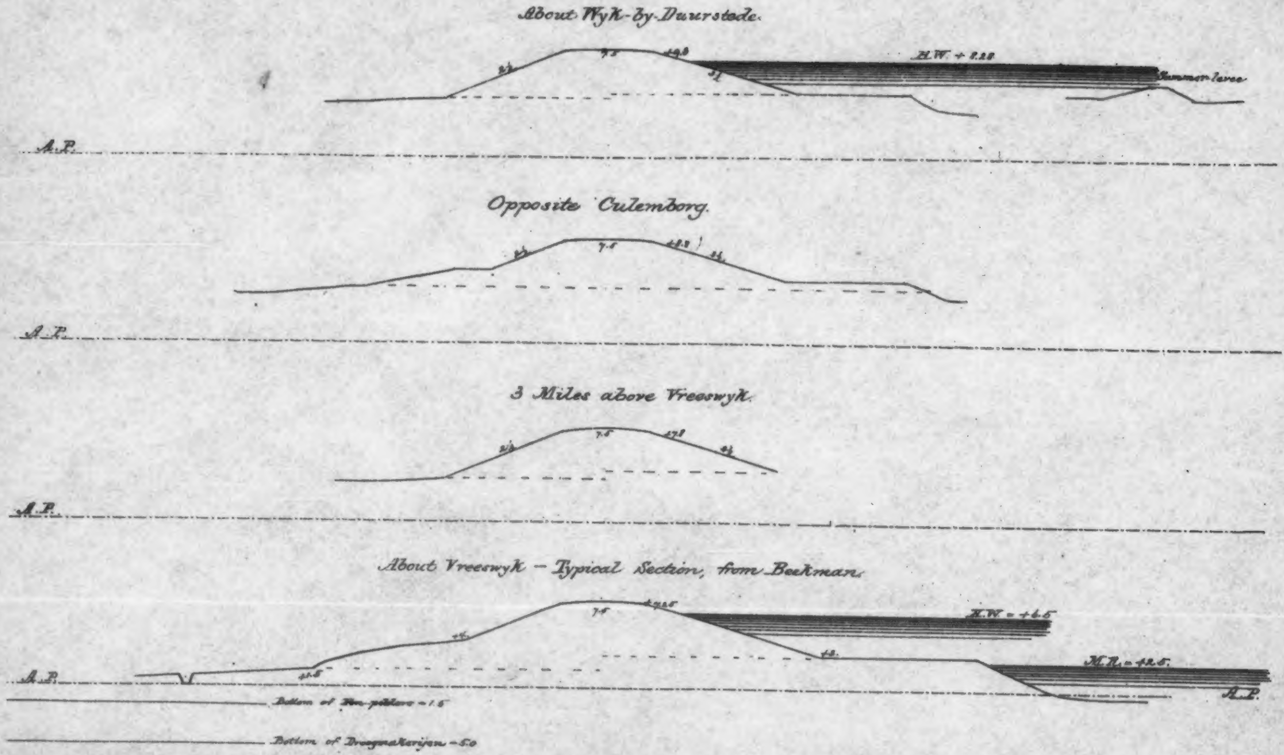
viewed with apprehension, though the author has never positively known them to be the cause of disaster. They may perhaps have been the source of breaks which have not been accounted for. They are treated in various ways: "hoops" are built around them; they are smothered by brush and earth; if they are surrounded by water, which is commonly the case, they are covered by mattresses of sacks, or, if not specially formidable, they are let alone and carefully watched. Very often they choke themselves up. They are known in local parlance as "sand-boils."

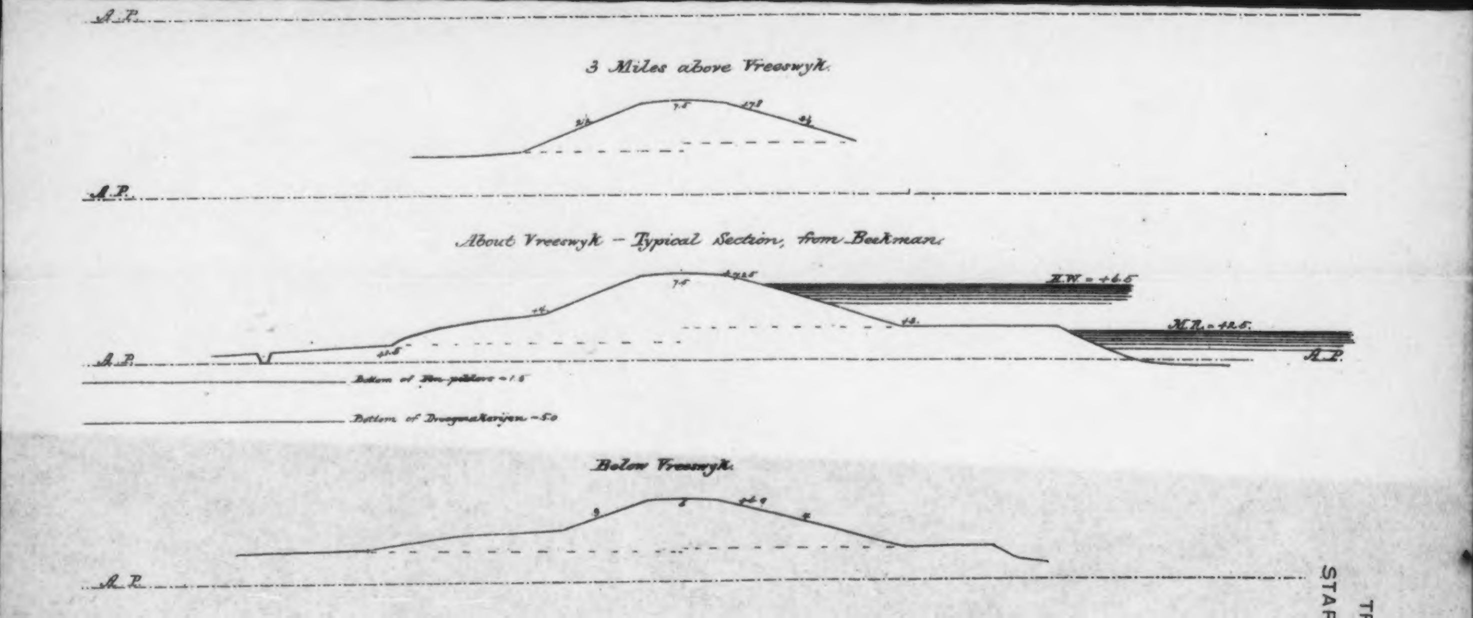
A peculiar cause of menace to the Mississippi levee is unsoundness. The system has grown from very small beginnings in a very short time, and it is only recently that it has been subjected to uniform and methodical control. "Before the war," it is asserted, the location and construction of levees was in charge of local boards of landed proprietors who employed engineers merely to stake off and estimate the work. In 1859, in Mississippi at least, the first attempt to organize the building of levees on a thorough and scientific scale was made, but it was soon interrupted. The labors of the Mississippi River Commission, however, gave a decisive impulse to careful and systematic work, by precise surveys of the river and a continuous line of levels. As the reclamation of additional territory and the more nearly complete confinement of the flood waters rendered necessary the heightening and strengthening of the levees, the latter soon attained considerable dimensions, and dangers were developed that had not been previously suspected, necessitating increased and minute precautions. It was not possible, however, to overhaul completely the older works, many of which were good and sound, while many were just the reverse, neither could it be said with certainty what was the exact condition in each instance, for most of the old records had disappeared during the war or the period of misrule and confusion which followed it. Consequently there is a doubt hanging over a great part of the older line, and many fine-looking works are more than suspected of having decaying wood, etc., in their interior. It has been attempted to overcome this defect by giving these suspected banks a great additional volume of earth, and no doubt this will eventually cure them, but in the meantime they sometimes develop weakness in unexpected places and occasionally they break without notice.

Formerly, the most common of all causes of breaks in the Mississippi

Sections of Dikes on the Lek.

Northern (Right) Bank.





3 Miles above Vreeswyk.
A.P.
About Vreeswyk – Typical Section, from Beekman.
H.W. = +6.5
M.R. = +2.5
Bottom of Droogmakerijen -5.0
Below Vreeswyk.

PLATE LX
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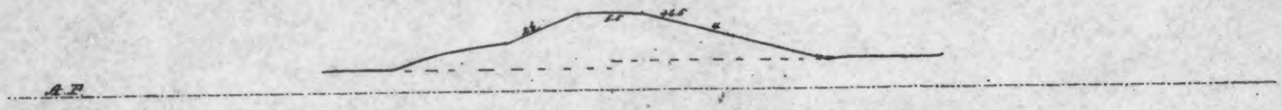
STARLING ON HOLLAND DIKES.

Sections of Dikes on the Lek.

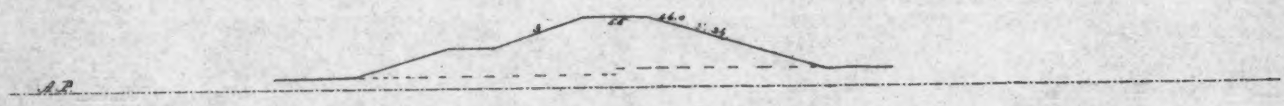
Northern (Right) Bank.

Near Jaarsveld.

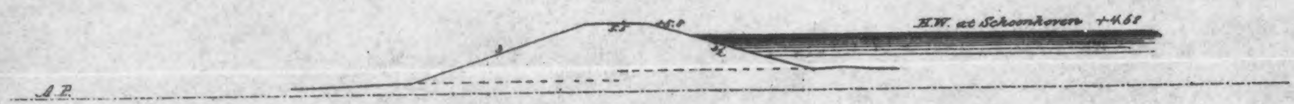


Below Jaarsveld.

Above Schoonhoven.



Above Schoonhoven.



Southern (Left) Bank.

Below Ryswyk.

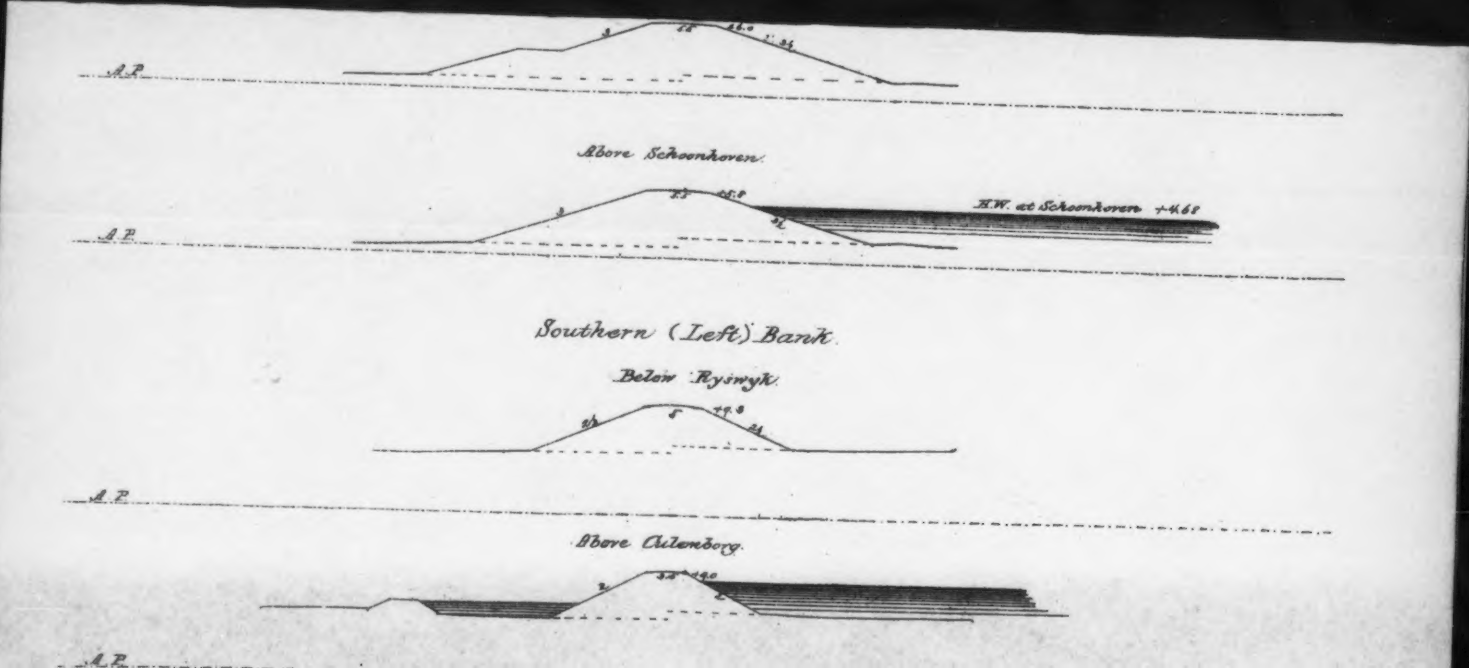

A.P.
Above Schoonhoven.
H.W. at Schoonhoven +4.68
A.P.
Southern (Left) Bank.
Below Ryswyk.
A.P.
Above Cülenborg.
A.P.

PLATE LXI
TRANS. AM. SOC. CIV. ENGRS.
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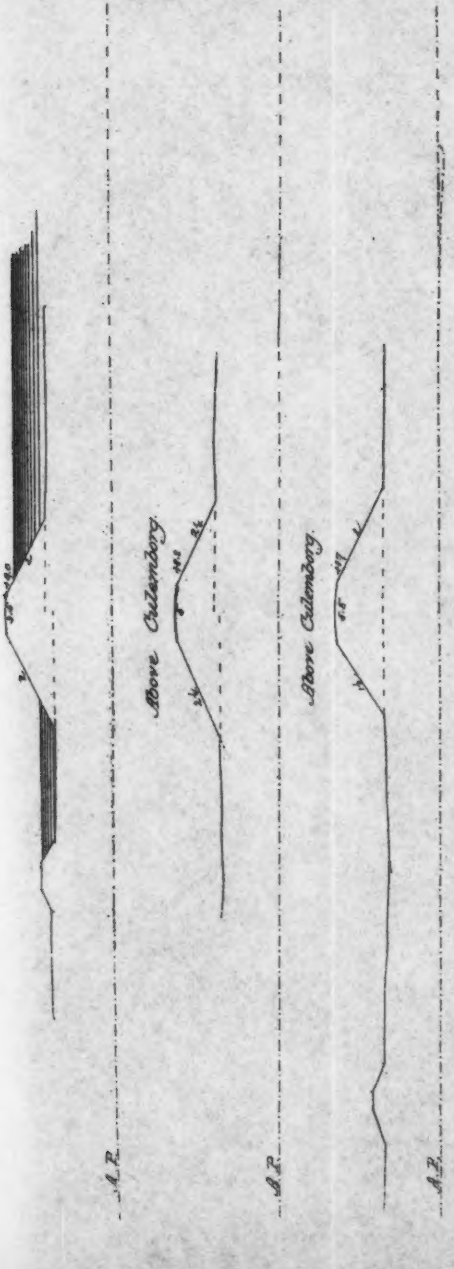
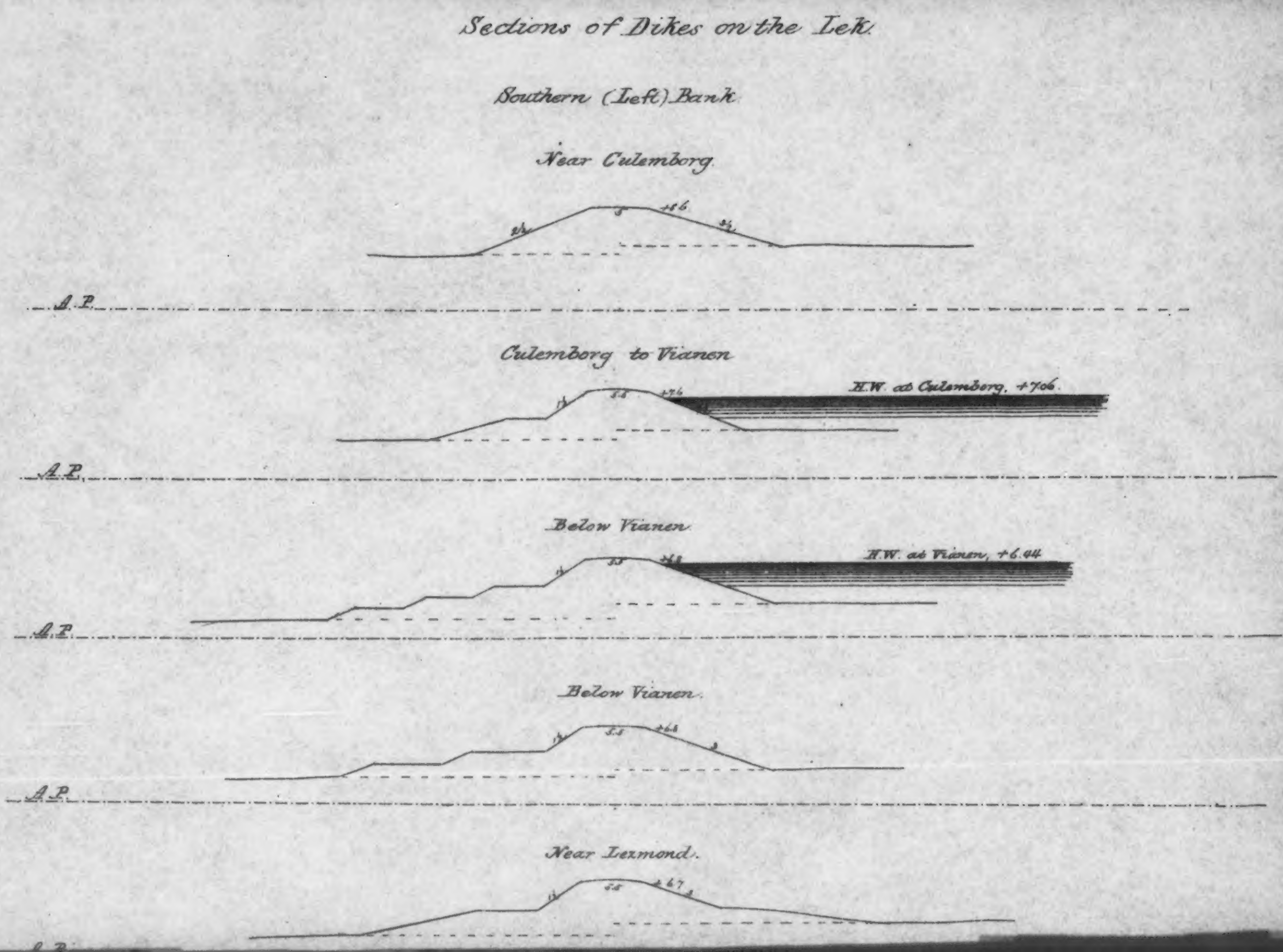
STARLING ON HOLLAND DIKES.



Sections of Dikes


Sections of Dikes on the Lek.
Southern (Left) Bank.
Near Culemborg.
A.P.
Culemborg to Vianen
H.W. at Culemborg, +7.06.
A.P.
Below Vianen.
H.W. at Vianen, +6.44
A.P.
Below Vianen.
A.P.
Near Lexmond.

PLATE
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STARLING ON H

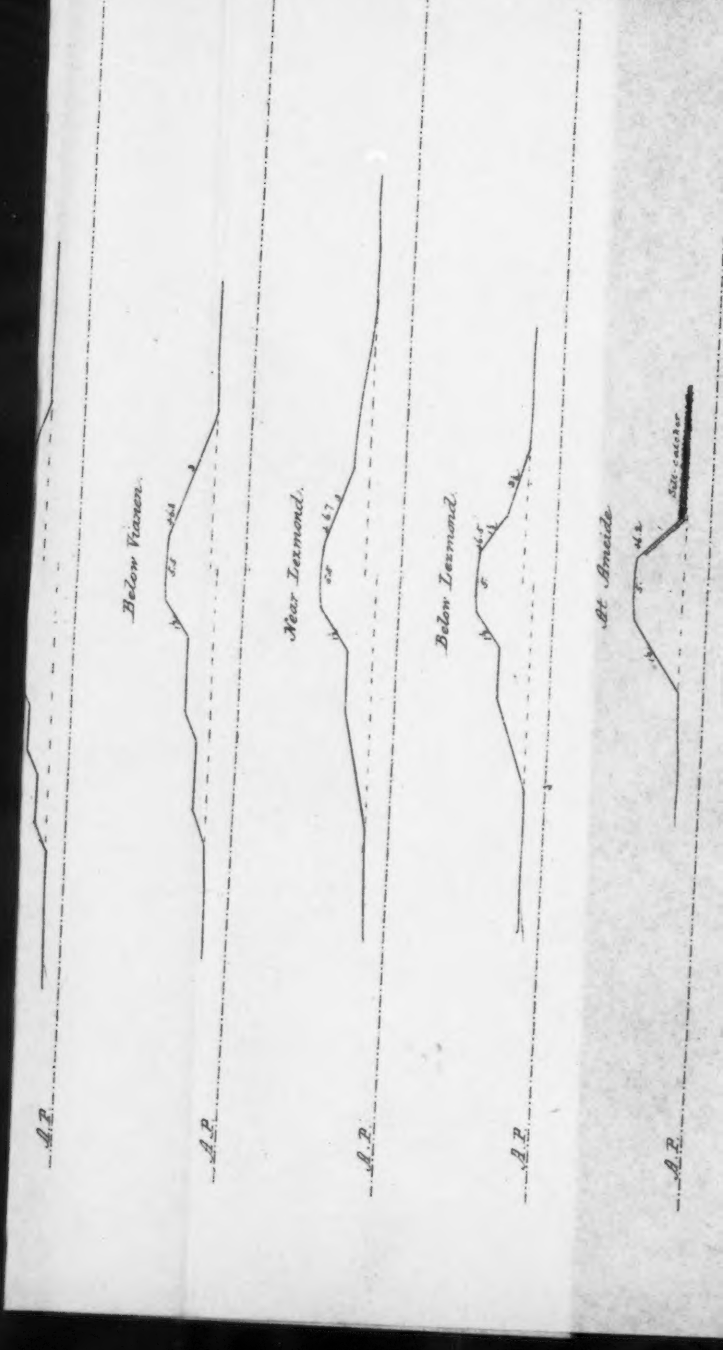
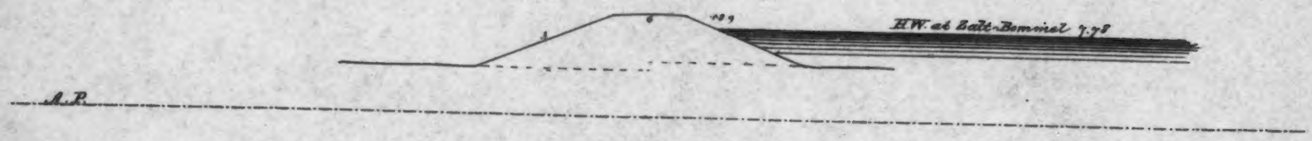


PLATE LXII
ANS.AM.SOC.CIV.ENGRS.
VOL.XXVI.No 534.
LING ON HOLLAND DIKES.

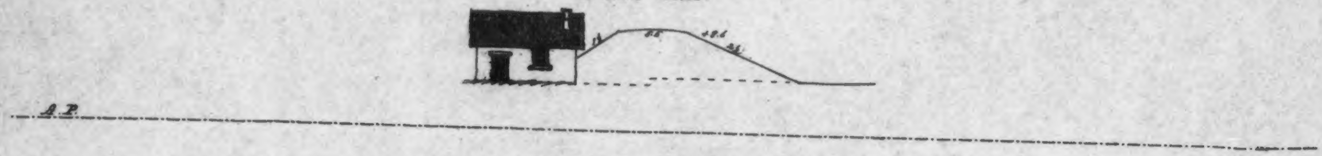
Sections of Dikes on the Waal.

Northern (Right) Bank.

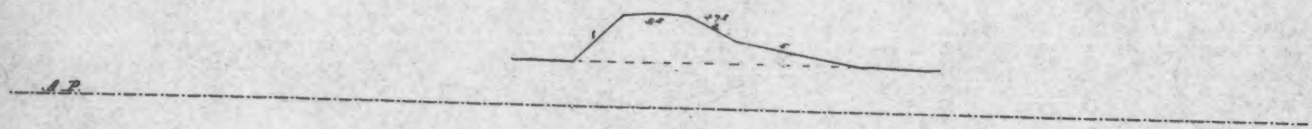
Near Tuil.



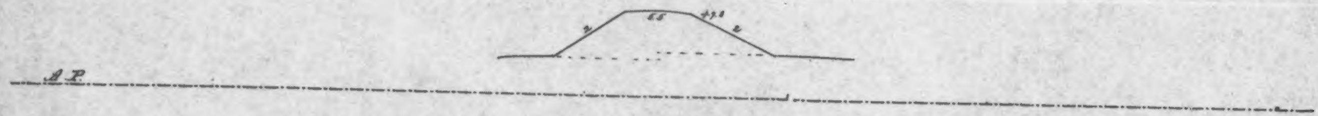
Below Tuil.



Between Tuil and Dalem.



Between Tuil and Dalem.



Above Dalem.

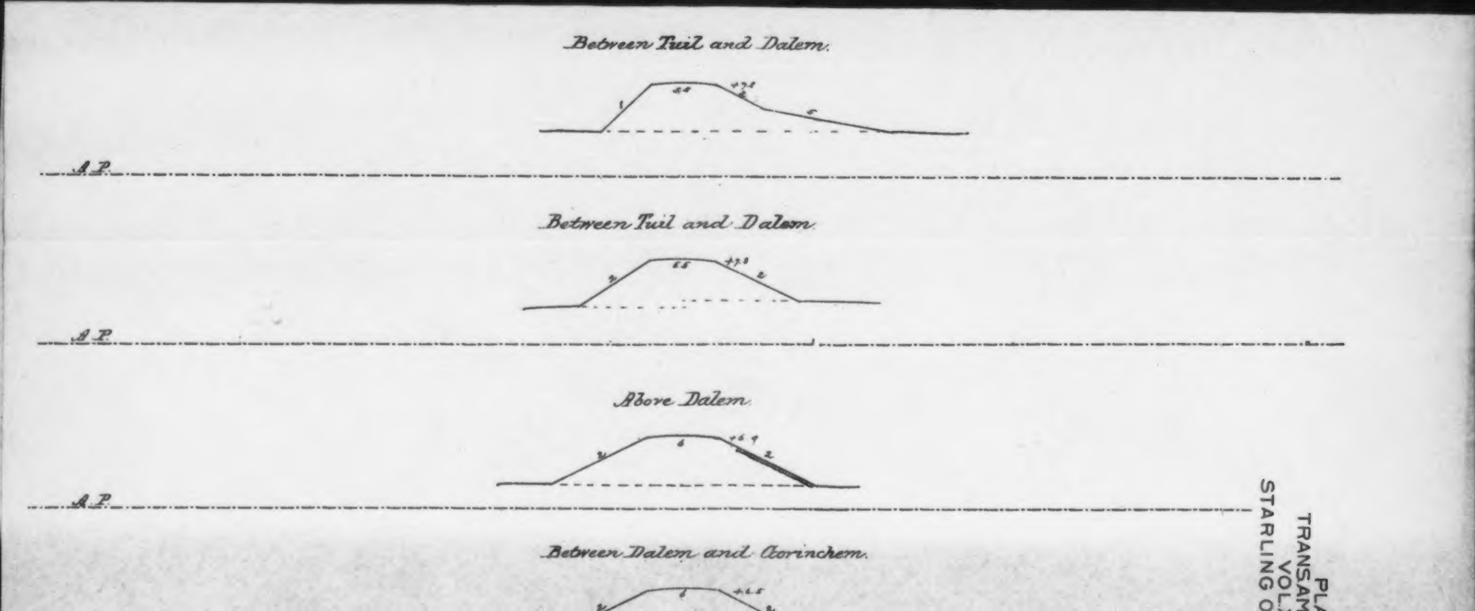

Between Tuil and Dalem.
A.P.
Between Tuil and Dalem.
A.P.
Above Dalem.
A.P.
Between Dalem and Gorinchem.

PLATE LXIII.
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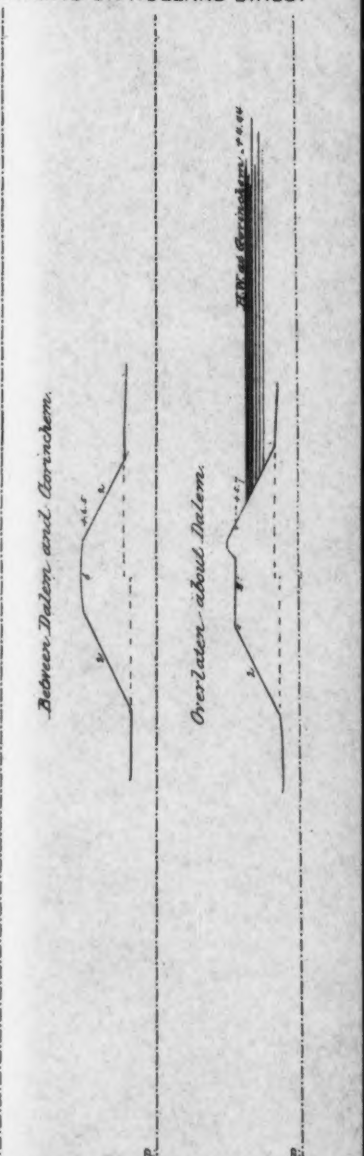
ARLING ON HOLLAND DIKES.

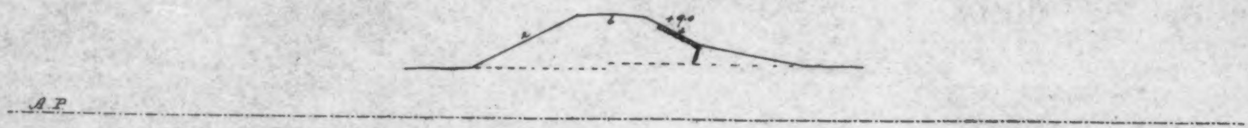


Sections of Dikes on the Waal.

Southern (Left) Bank.

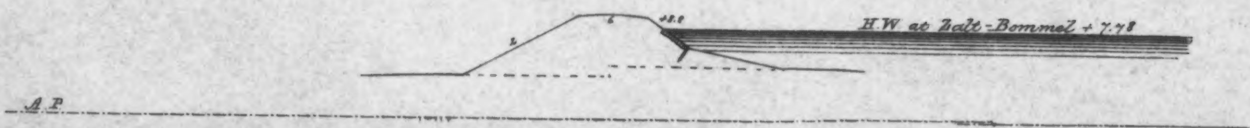
Below Fort St. Andries.

Between Rossum and Zalt-Bommel.



Heerewaarden Overlaat.

Below Zalt-Bommel.



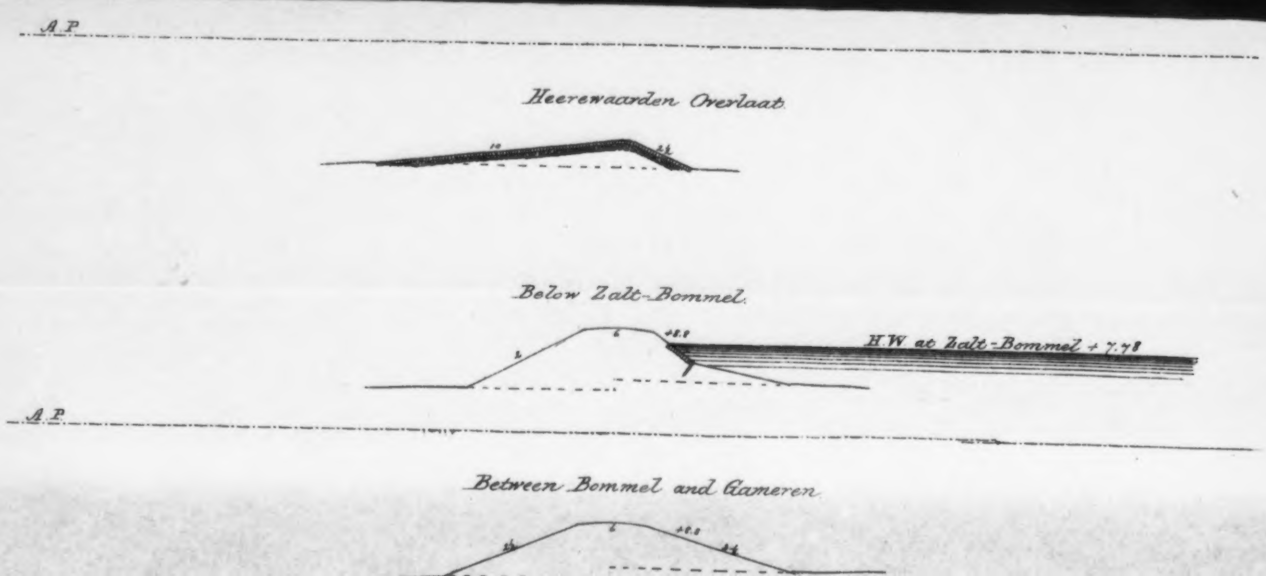

A.P.
Heerewaarden Overlaat.
Below Zalt-Bommel.
H.W. at Zalt-Bommel + 7.78
A.P.
Between Bommel and Gameren.

PLATE LXIV
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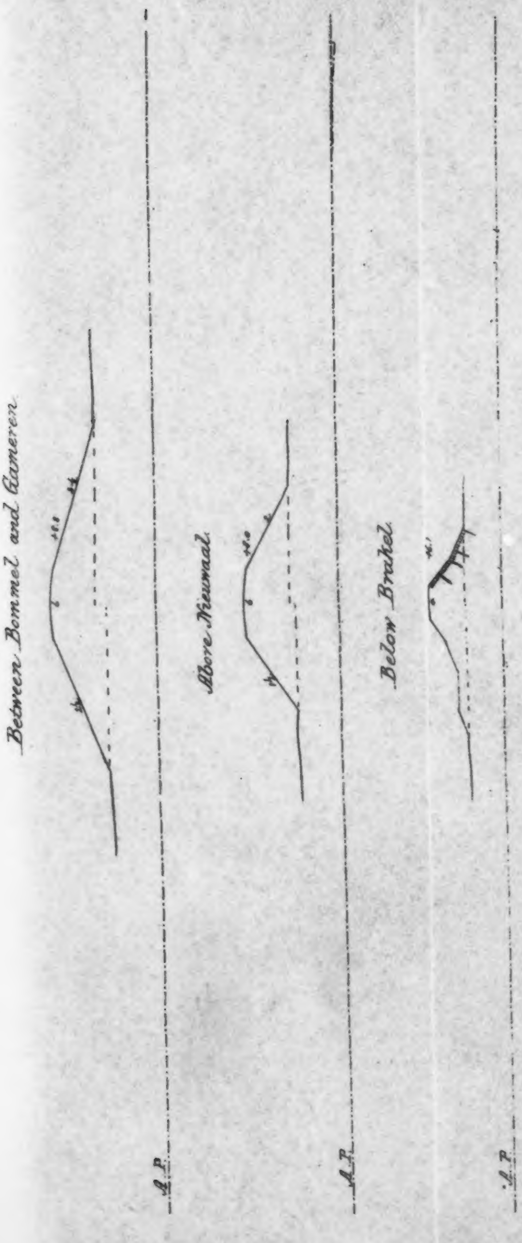
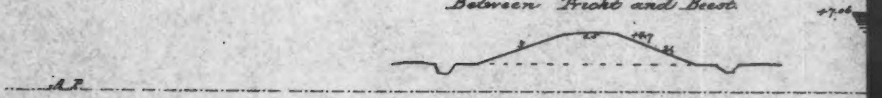
STARLING ON HOLLAND DIKES.



Sections of Dikes on the Linge.

Northern (Right) Bank.

Between Bricht and Beest.



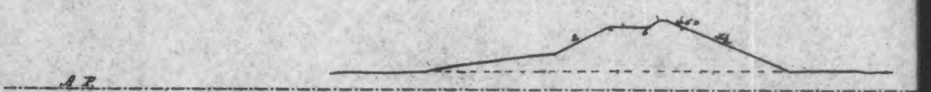
Between Bricht and Beest.

Above Beest.

Around Beest.

Overlaten between Beest and Asperen.

Dike (with overlaat) below Arkel.



Diefdyk.

PLATE LXV
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STARLING ON HOLL

f Dikes on the Linge.

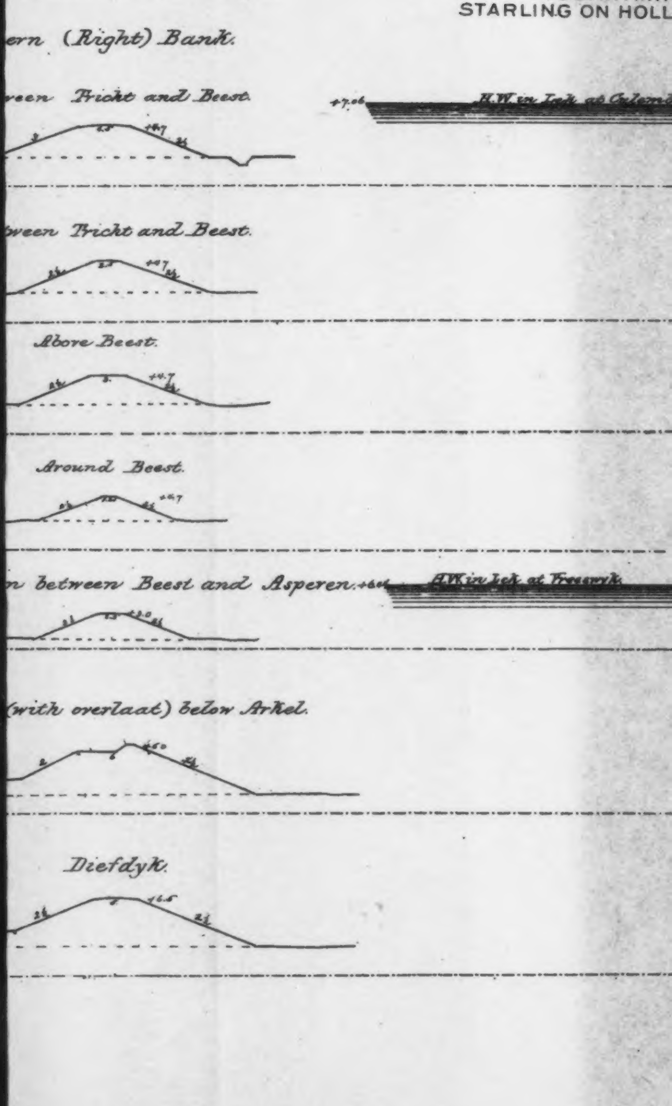
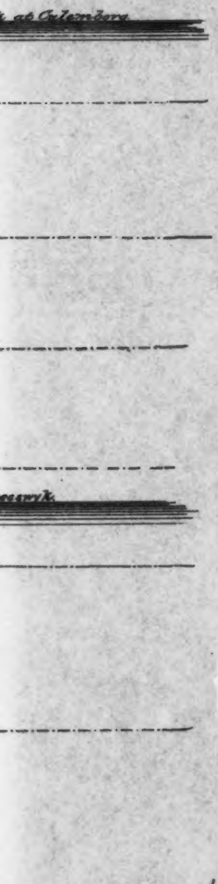
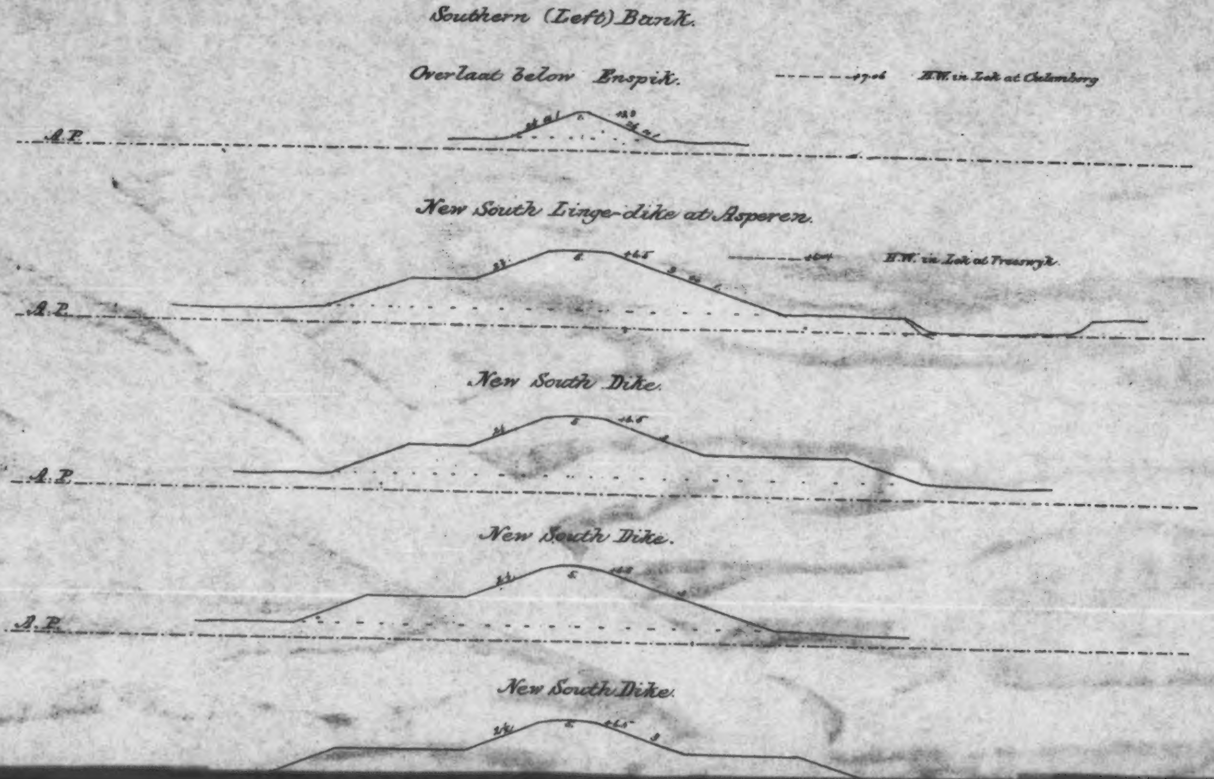


PLATE LXV
AM.SOC.CIV.ENGRS.
L.XXVI.Nº 534.
ON HOLLAND DIKES.



Sections of Dikes on the Linge



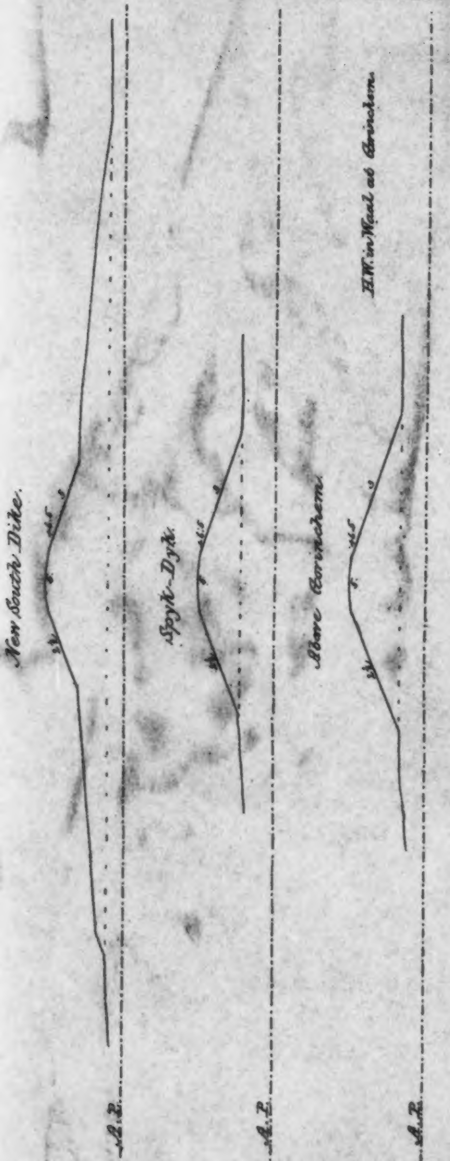
New South Dike.

New South Dike.

New South Dike.

New South Dike.

PLATE LXVI.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. No. 534.
STARLING ON HOLLAND DIKES.



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levees was simple overflow, the water running over the top of the dikes. In 1882 it is said that out of a great number of breaks in the levees of the Yazoo Basin (one of the great "bottoms" of the Mississippi), all but two were caused by overflow. To explain this statement it must be noted that this was the greatest flood which has ever occurred, so far as can be ascertained. So enormous was the volume of water, that in spite of the fact that there were almost no levees in Arkansas and a very defective line in Mississippi and Louisiana, the flood overtopped even those levees that were in existence. When it was found that the dikes were altogether too low, vigorous attempts were made to prevent the threatened inundation by devices similar to the *opkisting* of the Dutch, that is, by temporary topping, sometimes with plank, sometimes with sacks, sometimes with mere loose earth, cut in the haste of the emergency from the back slope of the levee itself. In this way the people managed to keep up with the daily rise by constant work, until the night of the 28th of February, when a violent storm of wind and rain arose, driving the waves over the weak and new work and completely sweeping it away. The water then poured over the levees broadcast, and the next morning there were 30 or 40 breaks, great and small, the overpour cutting away the back slope, already partially denuded of its sod, and enlarging the gullies in the crown. Breaks in sandy levees enlarged with great rapidity. Clay embankments stood much better, but could not resist very long. The Louisiana levees met with a similar fate. Some of the "crevasses" increased to enormous dimensions, 1 600 feet or so, and the total volume which went over the two banks was nearly half of the entire contents of the river.

Having discussed pretty fully the principles of dike construction, we may look at some of the types that present themselves in existing structures. The author visited the principal river-dikes and made notes and sketches of their actual dimensions from which Plates LX–LXVI have been drawn. In arriving at these dimensions, measurements were occasionally made, but not often. Generally they were estimated by the eye, a pretty well-practiced eye, however, in such matters.

The most important dike in Holland, after the sea dikes, is the dike which borders the northern bank of the Lek. It is also the most dangerous. For the distance from Amerongen to Krimpen, the Northern Lek dike has always been the cause of great solicitude to all Holland. Consequently, a vast deal of work has been spent upon it. Year after

year it has been raised, strengthened, provided with flatter slopes and furnished with banquettes.* Yet even now, so disastrous would be the consequences of a break in the northern dike, that it has been proposed to put sluices in the southern Lek dike, or even in emergency to cut it, so as to relieve the other side. The reason of this extreme solicitude about the one side of the river rather than the other, is that the Lek is the northernmost of the Dutch rivers (except the insignificant Yssel, whose valley is shut off from the rest by the highlands of the Veluwe), and the whole of the provinces of Utrecht and South Holland and even a portion of North Holland are dependent upon it—in other words, the richest and most valuable lands in the kingdom and also the lowest in situation. The drainage of this district, in fact, is mostly artificial by pumping, and many of the deep-lying polders, or *droogmakeryen*, as they are called, are from 12 to 18 feet below mean flood and far below low water. In case of a general overflow, then, this whole country would become a vast lake, with no natural exit for the water, and only to be emptied by the laborious, expensive, and, worst of all, slow process of pumping.

The northern Lek dike, then, and another very important dike, the new south Linge dike, also built on very bad soil, may be taken as types of the most recent and most careful construction under the most unfavorable circumstances. The borings at Vreeswyk show the nature of the underground of the northern Lek dike. Unfortunately, no records are at hand of borings on the banks of the Linge. Beekman merely says that the new southern dike rests on very bad soil and it is known that it gave way in 1820. The northern Lek dike, from Wyk-by-Duurstede to Vreeswyk, will average probably 12 or 13 feet in height, with a crown of about 25 feet (7.5 meters), slopes equivalent to about 3 to 1 on each side, back slope a little the steeper, so that usually the proportions are 2.5 or 2.75 to 1 and 3.5 or 3.25 to 1 respectively. There is a banquette on the land side all the way, with a crown of 10 to 20 feet and a slope of about 5 to 1, or dimensions equivalent thereto. Usually, indeed, there is no well-defined crown at all, but a convex slope all the way, and this is especially the case with the newer constructions. The banquette generally begins about 8 feet below grade. At Wyk-by-Duurstede a section of dike 600 feet long or so was built of brick, front vertical, back built in offsets, height about 8 feet, base about equal to altitude. Gap in the

* Beekman, "Nederland als Polderland," p. 46.

middle with grooves to receive stop plank, as hereafter noted. The river is crossed at Wyk-by-Duurstede by a flying bridge or ferry-boat moved by the current. Vreeswyk is connected with Vianen by a pontoon bridge like that at Cologne. One or two of the sections are movable, being worked in and out of place by an anchor and windlass. Some of the pontoons were of iron and some of wood. From Vreeswyk to Schoonhoven, which was as far down as the inspection extended, the dimensions are usually about these: Crown, 6 meters; slopes about 2.5 to 1 and 3.5 to 1; banquette, 12 to 30 feet wide, 8 feet below grade. This the author found about the rule. The crown has a single-track graveled road about 6 feet wide, sometimes a little broader, all the way from Wyk-by-Duurstede to Schoonhoven. There was an ordinary cable ferry from Schoonhoven to Nieuwpoort, the cable being of wire. The ferry-boat had almost a seagoing model, with a lee-board, which was used, as there was a brisk wind. The river is about 1 500 feet wide.*

The southern Lek dike, as it is of less importance, is generally inferior in dimensions to the northern dike. It is very irregular, having been worked on apparently, at different points and at different times, as emergencies arose or notable deficiencies discovered themselves, from weakness of soil or other causes. From a point opposite Wyk-by-Duurstede, or say Culemborg to Vianen, it would average: Crown, 5 meters; slopes, 2 to 1 and 2.5 to 1 or their equivalent; height, 10–12 feet, small banquette at intervals. From Vianen (opposite Vreeswyk) to Nieuwpoort (opposite Schoonhoven), same dimensions, with banquette of 12 feet crown, slope 3 to 1. Here it should be noted that in almost all cases the land on the river side of the dike is higher by perhaps 2 feet than on the land side, from silting up. Great pains are taken to promote this action by the building of "silt catchers" or low spurs, extending from the dike to the river bank. These spurs are constructed of brush faced with stone or brick rubble, sometimes merely with rough fragments or refuse. They are all but universal. Occasionally, close rows of willows are substituted for them, as is common on the upper Rhine. The author observed in a few places, on the dike he is describing, banquettes placed in terraces, two or three at a time, each perhaps 3 feet high and 12 feet wide. It is quite evident, in fact, that this dike is a kind of patchwork of the type very familiar to the Mississippi engineer, built as exigencies compelled and means allowed. In one

* See Plates LX and LXI.

place, a small interior dike was noticed, about 3 feet high and about 2 000 feet long, no doubt intended to form a basin or hoop, as has been already observed, to be filled with water for a counter-pressure. Neither the northern nor the southern dike has, as a general rule, any protection against winds except sod. Occasionally the southern dike, when it is "sheer," as the Dutch say, or has little foreshore, as at Ameide, is protected by a revetment of basalt. The crown has a graveling of 6 feet wide all the way. Most of the different types here noted are presented on the plates.* It is not intended at all to exhibit these as representations of the average dike, but only to show diversities of construction. Sometimes two or three of the types have occurred within half a mile.

The Linge dikes really belong to the system of interior dikes, and their mission (especially that of the southern dike) is not only to confine the water of the river which they inclose, but to serve as internal barriers against the spread of a possible inundation from a breach in the southern Lek dike or the northern Waal dike. The functions of the Linge dikes are somewhat complicated and are not well understood even by some of the Dutch engineers not personally acquainted with them. They will be considered later on.

The Waal dikes were examined from Tuil, nearly opposite Zalt-Bommel, to Gorinchem, on the northern bank, and from Fort Sint Andries to Woudrichem on the southern side, as well as from Sleeuwyk westward, along the northern boundary of the Biesbosch. The northern dike† has a crown of about 5 meters, slopes of about 1.5 to 1 and 2 to 1, the flatter slope being always on the river side, here and elsewhere, unless otherwise specified. Height 10 to 13 feet, varying all the time. Banquettes only occasionally and not large at that. Houses close on both sides, built on and in the slope of the dike habitually all the way. Crown graveled, of course. Slopes and banquette often cultivated. It will be observed that these dimensions are decidedly small, considering the height of the dike and the magnitude of the river which it is designed to confine. For this two causes may be assigned: First, it would appear that the soil on the banks of the Waal is stronger than usual. The author examined some pits near Fort Sint Andries and found excellent clay and loam as deep as the pits went, some 10 feet. (The pits were a long way off—perhaps 300 feet.) The brick of the Waal are famous for their

* See Plates LXI and LXII.
† See Plate LXIII.

strength. Second, he was informed that the Tielerwaard was not in as good financial or administrative condition as some of the other districts. His informant, who was merely his driver, being perhaps a good Republican, or knowing that the author was one, attributed this to the fact that the land in the Tielerwaard was in the hands of a few noblemen who are also the controlling power in the dike administration of the district. These, he said, do not like to put up their money, unless for their immediate benefit. Hence, the dikes in the vicinity of the residences, etc., are well maintained, but the remoter parts are neglected. The gentlemen ought, he said, to see the dikes of the Alblasserwaard! There, there are many small proprietors who contribute liberally to the dike fund. Hence, the Alblasserwaard is rich (that is, it may be supposed the dike administration is in a flourishing condition), and the Tielerwaard is poor in the same sense. There was no sign of its being poor otherwise. He said the Bommelerwaard, on the south side of the river, was in the same condition as the Tielerwaard. The author afterward saw some of the dikes of the Alblasserwaard, but cannot aver that there was much difference.

The south Waal dike,* for two miles below Fort Sint Andries, has a crown of 6 meters, and slopes of about 2 to 1 on each side. From this point to Zalt-Bommel the crown is 6 meters, while the slopes are about 2 to 1 and 3.5 to 1. Outer slope broken, steep part revetted with basalt to about 3 feet from the top. Banquette in places narrow, 10 feet or less. From Zalt-Bommel to Gameren, crown 6 meters, slopes variable, averaging about 2 to 1 and 3 to 1. Height, about 14 feet. From Gameren to Nieuwaal, crown 6 meters, slopes sometimes as steep as 1 to 1 and 2 to 1. Average, perhaps, 1.5 to 1 and 2 or 2.5 to 1. Height about 11 feet. From Nieuwaal to Zuilichem, crown 4 meters, slopes 2.5 to 1 on each side. Height, 10 to 12 feet. Trees on both slopes. From Zuilichem to Brakel, same dimensions. Below Brakel, crown 2.5 to 3 meters, slopes 1.5 to 1 and 2 to 1, faced with basalt outside; banquette 10 feet crown, slope 3 to 1, graveled and used as a roadway, contrary to the usual practice. Elsewhere on this line and generally the roadway is on the crown of the dike. The driver said that the dike broke at Brakel in 1871. He was, perhaps, mistaken in the date, but there is no doubt about the break. Beekman says the Bommeler-

*See Plate LXIV.

waard was overflowed in 1861.* Below Brakel the so-called Munnikeland dike is nothing but a *kade* or quay, as the Dutch call their low embankments.

At Woodrichem the Maas empties into the Waal, and the stream takes the name of the Merwede. The southern dike of the Merwede, where the author saw it, namely from Sleeuwyk to the Biesbosch, was 7 or 8 feet high, with a crown of about 6 meters, slopes of about 2 to 1, banquette a good deal of the way—front sometimes faced with basalt. In front of the Biesbosch (along the New Merwede) slopes 3 to 1 or more. The Maas dikes, at the only places that they were examined, that is, in the neighborhood of Bois-le-Duc ('s Hertogenbosch), were of pretty ample size, that is, with crown of about 4 meters and slopes of about 3 to 1. They are usually lower than those of the Lek and the Waal, averaging, probably, not more than 8 feet. The Maas is not completely diked. There are several gaps in the earthen barriers that confine it, on both the northern and southern banks. On the northern side it approaches the Waal, for a distance of several miles,† so closely that the two streams almost inter-osculate, and there has not been, until recently, any attempt to put partitions between them. On the southern bank there have been left, designedly, outlets to relieve the flood waters. Thus the dikes of the Maas, even where they exist, are not of the same primary importance as those of the Lek and the Waal. The country dependent upon them is limited in extent, the most valuable parts being the districts inclosed between the Waal and the Maas. It is not so formidable as either of the great branches of the Rhine, being hardly so large as the Lek, and less than one-third the size of the Waal. The chief interest which the river now possesses for us is derived from its remarkable outlet system, which, half natural and half artificial, is in existence in part up to the present day, and from the great effort now in progress to make a radical change in this respect, and consequently in the whole regimen of the lower river. This project will be mentioned more in detail hereafter.

We come now to speak of the internal dikes, namely, such as do not serve as a direct protection against the sea or river. These are mainly of two kinds—dikes properly so called, and *kaden* or quays, whose principal office is to protect the deep-lying polders from the

* "Nederland als Polderland," p. 50. (See Plate LXIV.)
† Six kilometers—say 3.75 miles.

waters which accumulate inside the dikes. Internal dikes are sometimes apparently the remains of former systems. Holland is intersected by former arms of the Rhine, and disused water-courses which were once living streams, and even after they ceased to be principal channels, yet had communication with the parent river in time of flood, and consequently had to be diked in like manner with it. These streams are now shut off by locks and dams, so that they are independent, but the dikes are still used in retaining the water at a high level, for purposes of drainage and storage, and also for additional protection in case of breaks in the main dikes. Indeed, this is now the principal function of the internal dikes; and for this purpose their original dimensions have been increased, until, in one notable instance at least, they are as strong as the outer dikes. This is the case of the Linge, previously mentioned. Others have been apparently very little modified, and they would be a very precarious dependence against overflow in the event of a serious breach in the main dikes. Such are the so-called High Rhine dike, which bounds the southern bank of the "Leidsche Ryn," the Prinsendyk, and the Yssel dikes above Gouda. Other internal dikes have been built for the express purpose of serving as a second line of defense or "interior retrenchment." These are sometimes, but not uniformly, kept up to the standard of the main dikes, and are not always to be relied upon. The Diefdyk is an example of the first kind, the Meidyk of the second.

The Linge dikes* play an important part in the system, and it is worth while to examine them a little, as an instance of the forethought and care which the Dutch engineers have bestowed in providing for all possible emergencies. The Linge is in itself an inconsiderable river, whose bed covers less than 50 miles in length, having its origin and its mouth in the largest of the so-called islands between the Lek and the Waal. It is, in short, merely the channel through which flows the drainage of the eastern part of the island, comprehending the districts of the Upper and Lower Betuwe, the land of Culemborg, the land of Buren, the Vijfheerenlanden† and the Tielerwaard. In summer it is a mere creek, especially in its upper part, almost going dry. In this portion of its course it flows between relatively high banks, so that it is not diked until it reaches Tiel, about midway of its valley. In winter, how-

* See Plates LXV-LXVI.

† So called from the *five lords* who first diked in the district—the lords of Arkel, of Vianen, of Hagestein, of Everdingen and of Leerdam. Beekman, "Nederland als Polderland," 49.

ever, the streamlet becomes a formidable river, as might be inferred from the breadth of the waterway allowed by the bridge at Geldermalsen, where it is crossed by the Rhine Railway. This bridge has 5 spans of 121 feet each. The floods of the Linge correspond, for the most part, to those of the great rivers. If these are so swollen that the "outerlands" between the dikes and the rivers are overflowed, then the Linge receives, besides the drainage from its own basin, the water that percolates through the sandy or gravelly strata under the dikes—leak water or sipe water—which may accumulate to an enormous amount, and swell the Linge to an indefinite extent. The conveyance of the drainage of the low lands to an elevated stream, 10 feet or so above the natural surface, is, of course, accomplished by pumping.

The Linge is not allowed to discharge naturally into the Waal. At its mouth, at Gorinchem,* there are two sluices, with the double purpose of keeping out excessively high water from the Waal, or holding back the flood water of the Linge, as either may be desirable. Should the Linge become dangerously high, by reason of heavy rainfall, with a corresponding amount of drainage from its valley and leak water from without, it may be discharged through these sluices, should the stage of the Waal permit. Should the Waal be too high, the Steenenhoek Canal has been contrived to carry the drainage to a point some 5 miles below Gorinchem. The fall between the latter place and the lower mouth of the canal is, at medium stage, 12 inches at flood and 28 inches at ebb, and at high stages the difference is still greater. The Linge water can thus be discharged at the mouth of the canal when it can no longer pass out at Gorinchem. There is a powerful steam pump at the canal mouth to give drainage at still more unfavorable stages.

The Linge is also of great importance as affording a prospective channel of relief from overflow water. Should a breach occur in the southern Lek dike or the northern Waal dike, in order to prevent the whole island from being inundated, the embankment called the Diefdyk† was constructed, as far back as the thirteenth century, joined to the southern Lek dike at one end and to the northern Linge dike at the other, and thus serving, in conjunction with the latter, to limit the extent of the overflow. It is especially desirable that the land to the west of the Diefdyk should be protected, as this (the Vyfheerenlanden and the

* Frequently shortened (always in pronunciation) into *Gorkum*.

† It probably took this name because it followed the course of the old Diefweg, or Thieves' Road.

Alblasserwaard) lies very low, and can be drained only by pumping. To this end, the Diefdyk has been strengthened, the northern and southern Linge dikes have been connected by a dam and a sluice across the Linge (at Asperen, near the southern end of the Diefdyk), and the southern Linge dike to the west of Asperen raised and enlarged. In addition to these precautions, a second line of dike has been constructed at a certain point on the south bank of the Linge, where the soil is particularly treacherous. This, the "new south Linge dike," is the largest and most elaborate work, except the sea dikes, that was met with in the Netherlands. It was estimated that it would average 16 feet high or more, with a crown of 5 meters, and slopes of 2.5 or 3 to 1 on the side next the Linge and 3 to 3.5 to 1 on the side next the Waal, with banquettes all the way on the Linge side and in places on the Waal side. Sometimes the banquettes are of extraordinary size—75 feet or so wide. Sections are shown on the plates.* The length of the line is about 14 000 feet. The driver said that the banquettes, or some of them, had only recently been added. Perhaps they have merely been enlarged.

The whole of the southern bank of the Linge, west of the Diefdyk, is guarded by very strong embankments. The dikes on the northern side, especially west of Arkel, are lower, and are intended, in case of necessity, to assist in relieving the Alblasserwaard. To the eastward of the Diefdyk, or of Asperen, the dikes on both banks are much lower, and in some places are even smaller than usual, being designed for the express purpose of allowing overflow water to pass over them easily. They are varieties of a construction called *overlaten*, over-lets, as it were, or outlets, formerly a recognized feature of the dike system, and still having a limited range of application for relief in case of overflow, or for artificial inundation for military purposes. There are fifteen of these between Asperen and Wadenoyen, part in the northern dike and part in the southern. They are in this case merely pieces of low dike, 2 feet or so under the grade of the adjacent parts of the line, topped so as to bring them to ordinary grade; the topping being always on the river side—that is, on the Lek or Waal side. This topping, being very slight, is easily cut or washed away and the overflow water given free sweep. If, now, a break occur in the southern Lek dike east of the Diefdyk, it will, if considerable, run over the overlaten to the east of Asperen, and fill

* Plate LXVI.

the upper channel of the Linge, but will be prevented from extending to the west by the Diefdyk, the dam at Asperen and the south Linge dike. It will be observed that the new south Linge dike forms with the old dike, called the Appeldyk, a basin. This basin is now flooded with water by overlaten at and below Asperen, thus creating a counter-pressure against the external water of the overflow, and supporting the new dike, which, in spite of its great proportions, is much distrusted, on account of the weak soil on which it rests. If the break be in the northern Waal dike, the condition is very similar.

When the rivers have begun to subside, the sluices at Asperen are opened and a portion of the overflow water discharged, through the bed of the Linge, at Gorinchem, and through the Steenenhoek Canal. Another portion is let out over the overlaten at Dalem and the military inundation sluices at that place. The overlaten alluded to are very much like those in the Linge dikes. They are four in number, and vary from about 500 to 1 100 feet in length. If the break occur west of the Diefdyk, it will be confined as before. As soon as it is possible to let out the overflow water, part of it can be discharged over the northern bank of the Linge, through overlaten, part discharged directly into the Waal below Gorinchem, in the same way. For this purpose there are provided so-called hulpgaten, or relief openings, which are portions of sandy levee, pitched with clay, which can thus be cut away or washed away in a short time.* Owing to the great depression of most of the tracts of the Vyfheerenlanden and the Alblasserwaard, however, there will be a large overplus of water that cannot be drained off in a natural way, but must be pumped out. For this reason, overflows in this particular region are more than usually dreaded. Wherever there are openings in the topping of the overlaten, as for pathways and the like, they are revetted with vertical walls of brick, with grooves to receive stop planks.

The railway embankments are capable of performing very important services as interior dikes. They are built very high and strong, and the openings in them are so constructed that they can be closed with timbers. The canal dikes are sometimes of sufficient size to be made available for internal protection, but not generally. The Y dikes belong properly, by their dimensions and their situation, to the class of river dikes. In many instances, as constantly in Zeeland, tract after tract has been redeemed

* Beekman, "Nederland als Polderland," 186. Id. De Strijd om het Bestaan, 144.

in succession from the sea, by diking in. The island of Walcheren is a perfect network of dikes, each field or separate domain being walled in by an embankment high and strong enough to keep out the sea, the old levees being left, in each case, in the interior, as the accretions progressed into the sea. It is evident that under these circumstances a breach in the outer dikes can produce only a limited amount of damage.

There is another class of interior embankments, which the Dutch do not usually call by the name of dikes, but kaden or quays. For the sake of convenience we may call them levees, reserving the term dike for the higher and stronger works, and especially for the main bulwarks against the outer water. There are essential differences in the functions and in the constitutions of the two classes of embankments, and it is perfectly proper that they should be distinguished one from the other. The polder levees are not primarily intended even as possible defenses from water from without, nor are they usually fitted for such a purpose. They are of comparatively late origin, and were evolved from the peculiar circumstances of individual localities. The rise and progress of the whole system of dikes and polders is intelligently and graphically described by Beekman, and the following details are taken from one of his books.*

"Let us consider first the low fen grounds. Here, there was once an inland lake, filled with fresh water, the bottom being composed of clay, deposited while the lake was yet in communication with the sea. The clay bottom lay 4 or 5 meters below ordinary flood. After that, the lake was shut off from the sea and filled with peat to the height of the surrounding water, and upon the peat arose thickets or woods, which sooner or later were felled by man or perished by decay. Rivers, arms of the Rhine, mightier than now, flowed through the forests in their beds of peat, and as they overflowed their borders, gradually covered their banks with a thin layer of river clay, superposed on the peat.

"In the time of the Romans, dikes were already begun to be built, but were used only as roadways. The land, whose topmost strata were not yet artificially dried out, and therefore had not shrunken or fallen in, was maintained, fen lands as well as silt lands, at about the height of mean flood. At higher stages it was overflowed. Only the higher diluvial† grounds, the dunes and the heath lands were inhabited. The hunter and the fisherman ventured into the swamp, with its dense woods and underbrush, intersected and covered with innumerable lagoons and ponds, and the herdsman made his way, especially in summer, to the

* "Nederland als Polderland," pp. 86 *et seq.*

† That is, the pre-alluvial lands or uplands, still of the Quaternary Period.

clay silt lands, and pastured his cattle on the higher spots, which by this very process became still higher. The woods on the fen lands gradually disappeared, the silt lands began to be cultivated, as soon as their marvelous fertility was discovered. Villages sprang up along the borders of the lowlands, and on artificially raised sites. In the time of the Counts, the earliest possessors of that title, whose domains were few, small and scattered, began to urge the reclamation of the lands. Without concert, and for private interests only, as population increased, limited tracts were diked in, solely for protection against the external water.

"The first dikes were nothing more than summer levees, which were overtopped by high floods and often destroyed. Those who built them acquired control of the lands protected, and maintained the dikes at their own expense. Thus arose dike law, which was granted only by the Count himself, to whom an appeal lay in the highest instance. Before the eleventh century there is no evidence of the existence of any dikes or dams (except in West Friesland), as is manifest, among other things, from the fact that no names, before that time, end in *dyk* or *dam*. In Holland, William II and Floris V first established systematic regulations for the control of the dikes. The first considerable river dikes were apparently erected between 1 200 and 1 400, though not in their present proportions. Greater concert of action appears after the formation of the great water districts (waterschappen)—that is, associations of lands having common interests as regards protection against the outer water. As the government became stronger, it erected more districts, and gave them even legal and criminal jurisdiction over infractions of dike law.

"Within the great external dikes, as early as the fourteenth, still more in the fifteenth, but especially in the sixteenth century, the fen grounds, including those covered with clay deposits from the rivers, were gradually surrounded by levees. This shutting off had for its object the entire control of the internal water—the levees excluding the outer water and permitting the ejection of that from within. The processes for the furtherance of the latter object were at first very imperfect, depending mostly on hand appliances, and it was not till after the invention and improvement of windmills that the draining of polders began to be accomplished in a satisfactory manner. The improvement came none too soon, for the necessity of thorough drainage was becoming urgent. As soon as the fen lands began to be systematically drained, the spongy crust which constituted their uppermost stratum, being deprived of its water, shriveled up and fell in, thus making the surface still lower, and compelling a resort to diking in as an indispensable condition of reclamation. In this way all the fen grounds, including those covered by river deposits, were gradually surrounded by continuous levees. They became *polders* and their surfaces sank below mean flood.

"A polder is a piece of land encircled by levees, for protection against water from without and control of the water within. Most of the polders owe their origin to the years since 1600. The great sea and river dikes were then in a condition to afford protection against all but extraordinary floods. But it became evident that, even within the great dikes, the tracts which were not contiguous to the highlands must be included within levees if they were to be kept dry. The fen polders, by the process described above, had become so low that they were no longer susceptible of natural drainage. Their bottoms lay, for the most part, about 5 feet below mean flood. Such lands could be drained only by artificial means. In many polders the peat had been cut away and sold as fuel. It is true that man and his cattle may make excellent pasture and arable land out of fen land, witness our famous Dutch meadows; but this is a work of time, and our old-time inhabitants were bent on present profits. The thick layer of peat, 8 to 13 feet deep, represented a considerable sum as turf. So, many polders became and remained deep puddles. This practice is no longer common. It has been discovered that the transitory profit of turf making is followed by a more permanent gain, in the exposure of the stratum of rich clay which lay beneath the peat—once the bottom of the inland sea. For many years past it has not been permitted to cut away the peat except upon an undertaking to drain the pools thus created. To meet the expense of this process a fund is provided, from the sale of the turf, without which permission is not conceded to remove the peat, and, beside this, a security fund for the proper execution of the necessary work during reclamation. After reclamation, all expenses are borne by the owners and the security fund is returned."

Polders produced by the cutting away of turf are called by a distinctive name. They are *droogmakeryen*—from *droog maken*, to make dry.

"There is another way in which droogmakeryen may be formed. There are lakes or ponds, such as the Haarlem Lake, the Zuidplas, and the multitude of lakes in North Holland, north of the Y, in which the peat which formerly constituted the bottom has been cut away by the action of the water during storms, etc., through the lapse of centuries. If these bodies of water are within the limits of the old inland sea and consequently have a good clay bottom, they may be reclaimed. Frequently other causes conduce to this result—as happened in the instance of the Haarlem Lake. It is found that on all considerable sheets of water, the wind has a very perceptible effect in raising the surface of the water in the quarter opposite to that from which it is blowing. If the lake be very large, this elevation of the water surface may proceed to a dangerous extent. In the case of the sea, it may amount to as much as 10 feet. It is, of course, accompanied by a corresponding depression

on the other shore. In the Zuider Zee, when a heavy west wind is blowing, the water is sometimes lowered 8 feet on the west coast and raised as much on the eastern. In November, 1836, the Haarlem Lake so far overflowed its northeastern shore that Amsterdam was in great danger, and in December of the same year the water ran over on the other side and inundated 20 000 acres of land and a part of the City of Leyden. Droogmakeryen, then, are defined to be polders that have been denuded of turf and pumped out—thus deep basins, with their bottoms lying 13 to 18 feet below mean flood. They are found almost exclusively in North and South Holland, and are particularly numerous between Amsterdam and Leyden, and between Leyden and Rotterdam. The lowest are in South Holland, and among them, particularly, the Prins-Alexander polder and the Zuidplaspolder, which lie near the lowest of the limits given above.

"The question naturally arises: How are these ponds made dry? With what appliances? What becomes of the water?

"First of all, the tract to be drained must be shut off from the surrounding land and water. This is accomplished either by the construction of a ring dike around the whole pool, or by making use of existing elevated roadways and levees, after enlargement and raising, or by a combination of the two methods. The earth for the ring dike must sometimes be obtained, partially at least, elsewhere, but is usually taken from a ring canal, running outside of and parallel to the levee, serving as a means of communication in place of the late pond, and as a receptacle for the water during the "dry making" and afterward for the maintenance of the polder in the same state. Sometimes the water is conveyed directly to existing water-courses, and through them to the open river or the sea. During the process of dry making there are frequently many troubles to encounter—mostly of a technical nature. For instance, buildings in the immediate neighborhood of the pond, or situated on islands lying therein, are in danger of settling or even of falling in, as the ground on which they rest is deprived of the support of the water which it lately had. Precautions must therefore be taken or indemnity assured where such conditions are presented. Furthermore, the lake may have served as a reservoir for polder water, etc., and some compensation must be provided for this loss. Account must be taken of leak water, which sometimes, in sandy soils, percolates under the ring dike and finds its way into the polder."

The emptying of the basin was formerly accomplished by means of windmills; now, the end is more speedily attained through the agency of steam. The machinery serves afterward to keep the polder free of water. As soon as the ground begins to show, a start is made toward the parceling out of the polder, that is, the digging or dredging of

ditches, which divide the polder into lots. The ditches serve to conduct the water that collects in the polder to the pumping works, which are placed around the periphery thereof, and which maintain the water at a definite distance below the surface of the ground. The ditches are of various dimensions. There are large canals, 8 to 12 meters wide, which lead directly to the pumps; into them empty other ditches, 6 to 8 meters wide, which are themselves the recipients from another system, running perpendicular to them and of still smaller dimensions, at intervals of 100 to 200 meters. Between these latter and parallel to them are two other systems, of breadths respectively of 3 or 4 meters and 1 meter. Each of these kinds of ditches has its appropriate name, which has no English equivalent. The surface of the drains collectively amounts to one-tenth or one-twelfth of the whole polder. The first harvest (usually a very abundant one) is obtained by breaking down the luxuriant growth of weeds which first appears, covering them with soil from the ditches and seeding down. This procedure, to obtain arable land, is termed *zwart maken*—making black.

There are also sea polders, obtained by direct reclamation from the ocean, as has been previously noticed. This process is still going on in Friesland, Groningen and the islands of Zeeland. Most of the sea polders discharge their water in the natural way, that is, without pumping, through sluices or culverts; some of them, however, have shrunken or fallen in, like the fen polders, and have to be drained into a higher level, and of course by artificial means.

After the late lakes or ponds have been made into dry land, they must be maintained in a proper condition, that is, provision must be made for the rain water that falls and the leak water that finds an entrance from outside. It is well known that evaporation in the long run nearly equals rainfall, but in the summer months it greatly preponderates, in the winter it is very small, and there would naturally be an accumulation during the latter months, just at the time that it would be most inconvenient, namely, during the plowing and planting season of the spring. Again, should excessive droughts prevail during the summer, there may not be a sufficiency of moisture in the soil for the crops. It may be necessary, therefore, to admit water into the polders. This was notably the case in the hot and dry summer of 1868. At Utrecht, in five months, the evaporation exceeded the rainfall by 23 inches. In that year, 15 800 000 cubic meters (about 558 000 000 cubic

feet) were let into Haarlem Lake polder alone. In other words, as has been said already, the polder water must be controlled.

The sea or the open rivers into which eventually all the polder water is discharged, is called the *outer water*. Leaving out Friesland, Groningen and Overyssel, this comprehends the Lek, the Waal and the Maas in the lower portions of their course, and the Yssel of Holland below the dam near Gouda, besides the North Sea and the South Sea (the Zuider Zee). All the other water in North and South Holland and Utrecht to the west of the Vecht and Vaartsche Ryn is dammed off and stagnant, and is called the *inner water*.*

The rain water sinks through the ground to the level at which the soil is already saturated, and then flows laterally into the complicated system of ditches already mentioned, which hold it as temporary reservoirs. The water must be maintained in these ditches at a certain level, which is, for meadow land, from 12 to 20 inches, and for arable land, from 20 to 40 inches, below the natural surface, so that the roots of the crops may not be continually in the water, but yet may be supplied with sufficient moisture. Especially toward spring must the requisite elevation of the water be secured and maintained. This elevation is called the summer level of the polder. It is different for each polder, according to the height of the ground surface and the use which is to be made of the land, and is officially established by the local Direction. In many polders there is also a winter level, which is lower than the summer, to allow for a greater probable rainfall. If the water in the ditches begins to get too high, it must be conveyed, directly or indirectly, to the higher-lying outer water. As there are but few polders that lie close to the sea or rivers, the water is not usually discharged immediately into them, but is pumped provisionally into an elevated reservoir outside the polder, entirely shut off and hence stagnant. This reservoir may be a ring canal, if the polder have one, or a navigable canal, or a former river, as the Old Rhine, the Amstel, the Gouwe, the Vecht, which have been dammed off for this express purpose, or a lake or pool, etc. Generally the same reservoir serves for more than one polder, sometimes for a considerable number. Usually, the reservoir itself is not confined to one body of water, but consists of several contiguous and connected pools, maintained at an elevated level, which is the same for them all. In fact, all the permanent water-courses and

* Beekman, "Nederland als Polderland," p. 103.

reservoirs of the district which are capable of being maintained at a high level are made to form parts of the system, and are called by the Dutch collectively the *boezem* of that district.* This term corresponds to our English word *bosom*, and, as the latter has no technical meaning, it may be used for its Dutch equivalent. The bosom of the district called the Amstelland consists of the following water-courses: the Amstel, the Drecht, the Kromme Mydrecht, the Angstel, the lake of Abcoude, the Holendrecht and the Bullewyk, the Oude and the Ryke Waver, the Winkel, the Gein, the Smal Weesp, the Gaasp, the Weesp and Muid canals, the Diemen, the Nieuwe Diep, the ring canals of the Bylmer and Diemer lake polders, and a part of the ring canal of Amsterdam. As each bosom thus has many branches, it is possible for many different polders, having different levels, to discharge all their superfluous water into the same reservoir. It is evident that the bosom waters, lying as high as they do, must themselves be inclosed between levees.

From the bosom the water must be discharged, at one or more points, into the rivers or the sea. The Rhineland bosom has four such points—Spaarndam, Halfweg, Katwyk and Gouda. What the quantity of the discharge must be is easily gathered from the fact that the reservoirs sometimes receive daily from the polders more than 7 000 000 cubic meters—say 247 000 000 cubic feet. Generally, the discharge from the bosom into the outer water may occur in the natural way, by opening outlet sluices. The water surface of these bosoms which empty into the sea is maintained at a height not much below mean flood, and, consequently, the gates may be opened some hours before ebb, and may run for a considerable time. On the rivers the discharging points are placed as far down as possible, and independent, in a measure, of floods from the upper waters. We have seen, in the instance of the Steenenhoek Canal, the advantage of selecting points well down the river, and the pains that have been taken to secure them. There are only two outfalls on the coast of the North Sea, namely, Ymuiden and Katwyk, and at both these places the ebb is very low—lower than in the Zuider Zee. This well-known fact had long pointed out Katwyk as the outlet for the Rhineland district. Nevertheless, there are times when natural drainage is impossible, namely, when landward storms prevail on the sea, and when the rivers are at high flood. This condition may prevail for many days. To be certain, then, of keeping the polders free from superfluous

* Beekman, op. cit., p. 107.

water, auxiliary means of emptying the bosoms must be provided. These means are powerful steam draining machines—and such have accordingly been erected at all the principal discharging points, as, for instance, at the four outfalls of the Rhineland bosom just mentioned, Spaarndam, Halfweg, Katwyk and Gouda. The author saw all of these except the last. They are of the wheel pattern, presently to be mentioned, and have each a capacity of about 100 000 cubic meters per hour, raised about 1 meter or 1.20. It was found that, before the erection of the steam machine at Katwyk, the water in the bosom could not be completely controlled. Not only on account of high stages of the outer water were the steam machines found serviceable, but even at ordinary stages, to free the polders more speedily of the excess that embarrassed them. They are thus used in conjunction with the sluices. Even before the building of the fourth machine, the Rhineland bosom, from 1858 to 1868, discharged annually 300 000 000 cubic meters naturally and 190 000 000 artificially. The machines worked sixty to one hundred days in the year.*

The ratio between the bosom and the land which it drains is very variable, and depends much on the facilities for emptying the bosom. Rhineland has a land surface of 192 000 acres and a bosom surface of less than 9 000. Delfland has 75 000 acres of land and a bosom of less than 1 000. The draining of Haarlem Lake greatly reduced the reservoir surface of Rhineland, which was compensated by the erection of the steam drainage works at Spaarndam, Halfweg and Gouda, and the enlargement of the inner sluices at Katwyk. Polders which lie very deep cannot be made to discharge all at once into the bosom—at least with ordinary appliances. The water must then be brought up to a series of levels—sometimes as much as four, as formerly in the Zuidplaspolder, and still (it is believed) in the Schermerpolder. Flights of two or three levels are very common.

The appliances just referred to are of two kinds, one having wind for the motive power, the other steam. The Dutch call all these machines *molens* (mills) more specifically, water mills. There are wind watermills and steam water-mills. The mills are usually placed at the lowest part of the polder, that the drainage may flow naturally to them. In extensive polders they may be situated at several points, to avoid the inconvenience of draining to one place, and to obviate the effect of the

* Beekman, op. cit., p. 108.

wind, which might operate to accumulate water at the side of the polder remote from the mill, and empty the ditches on the side adjacent to it. There may also be several mills at one point, constituting a gang or flight, as has just been explained. Windmills have been in use since 1308, but it was not until 1573 (it is said) that a Fleming made the discovery that it was not necessary to turn the whole mill to the wind, but only the cap, which he made to revolve for the purpose. It is certain that rapid progress was made shortly after that time in the draining of lakes and pools—in which the famous engineer and millwright, Jan Adrianszoon, surnamed Leeghwater (Empty-water, as it were), took a particularly prominent position.

Two principal varieties of windmill are in common use—screw mills and scoop wheel mills. In either case, the ditch which conveys the water to the mill is contracted to a narrow width and revetted with stone or brick, with vertical walls. The screw or the wheel fits closely into this space, and conveys the water to a higher level, where is another waterway, provided with a valve opening outward. This valve prevents the bosom water from running back into the polder when the mill is not in action. When it is working, the head of water inside soon gets higher than the bosom water and opens the valve.

The screw is formed by plank fastened spirally round a shaft, forming a double or treble helix, like an auger. It is placed at an angle of 25 or 30 degrees with the horizon, with its lower end beneath the surface of the polder water and its upper end higher than the outer water. It revolves in a chamber of masonry, which it fits very closely for a part of its course. Its action needs no explanation. In large windmills the screws are from 5 to 6.5 feet in diameter.*

Scoop wheels have a diameter of from 3 to 8 feet, depending on the lift which is required. The apparatus consists of a heavy shaft with twenty or twenty-five buckets, about 1.5 feet wide, with a dip of 2 or 3 feet, and not radial, but inclined to the radius, to allow a freer clearance of the water. The axis of the wheel lies a little (1.5 to 3 feet) above the inner water, and the wheel itself fits as closely as possible into a chamber or trough, which conducts the water to the upper level.† In some mills there are two or three wheels, frequently of different widths, either or all of which may be worked, according to the strength of the wind.

* See Plate LXVII (from Beekman).
† See Plate LXVIII (from Beekman).

PLATE LXVII.
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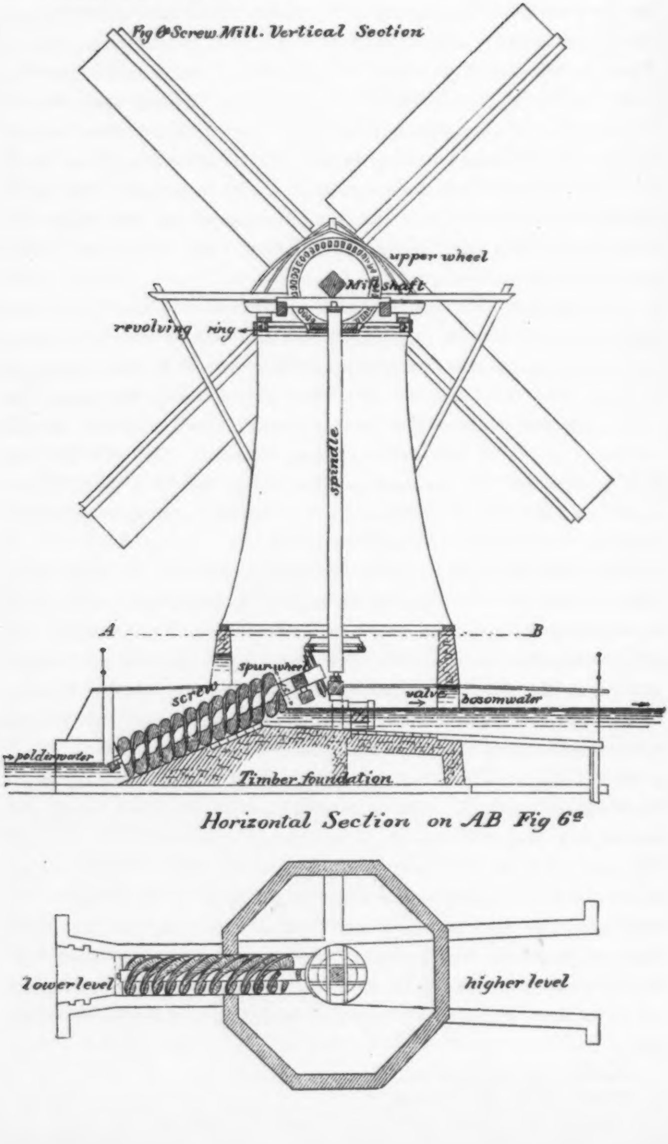
STARLING ON HOLLAND DIKES.

Fig 6a Screw Mill. Vertical Section



Both wheels and screws are much used, the latter principally in North Holland, Friesland and Groningen. Wheels are the older. They have a lift of about 5 feet, at most 6.25, though with less efficiency at that height. Screws will raise water as much as 12 or 15 feet; nay, there are two in the Rhineland district that have a lift of 17.5 feet. They are coming more and more into use, in many instances replacing wheels. In Friesland they are used almost exclusively.* A variety of screw is much used for drainage on a small scale, and was often observed as employed by contractors for draining the interior of coffer-dams, etc. It was, however, a genuine Archimedean screw, the thread not playing freely in a close chamber, but being boxed in by a cylindrical casing of plank, which revolved with the axis. It was operated either by steam or by hand, as might be required. In the latter case a hand crank was simply attached to the shaft. Such screws are called *tonmolen*, barrel mills.† Pumps are not well adapted to use with windmills.

In large windmills, as was before observed, only the cap revolves, with the axis and the arms, so as to place the axis parallel to the direction of the wind. This is managed by hand. Smaller machines are sometimes made self-adjusting, as is so commonly the case in America. Sometimes the whole body of the mill revolves. The length of the double arms in the largest mills is as much as 100 feet. Such mills are built of wood or stone. The former cost about $12 000, the latter somewhat more. The arms or vanes consist of an open framework like a tennis racquet, on which are spread canvas sails when the mill is in motion. When it is not in use, the sails are furled or unbent altogether. In the Rhineland district there are two hundred and sixty windmills for drainage, exclusive of Haarlem Lake, which is drained wholly by steam.

Steam power is coming more and more into use for the drainage, not only of the bosoms, but of the polders, especially when the latter are extensive. One great advantage of steam is that it can always be used, whereas it has been found in Schieland that only 130 days in the year furnished sufficient wind power to drive the mills. On the other hand, steam costs money, wind can be had for nothing, so there are cases in which the latter is preferable. With average rainfall, a polder steam mill may work about fifty days in the year; under unfavorable circumstances,

* Beekman, "Nederland als Polderland," p. 114.
† Storm-Buysing, Waterbouwkunde, ii, p. 385.

PLATE LXVIII.
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Fig. 7a Scoop-wheel Mill Vertical Section

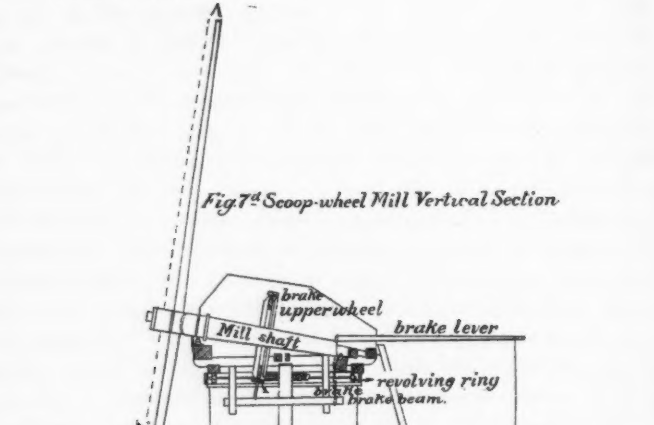
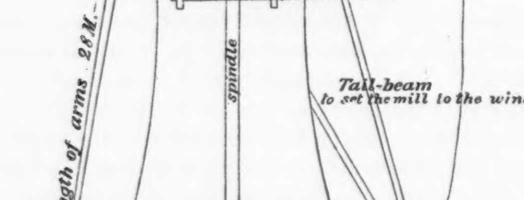


Fig 7 Horizontal Section on AB



sixty or seventy.* With steam may be used wheels or screws, as with wind power, and also pumps. Centrifugal pumps especially are coming much into vogue. Nevertheless, nearly all the great draining machines that were seen were wheels. There are wheels at Spaarndam, Halfweg, Katwyk, Amsterdam; centrifugal pumps, it was said, at Schellingwoude; lifting pumps at Haarlem Lake.

The following memoranda are from notes taken on the spot:

The apparatus at Katywk consists of six wheels, each 9 meters in diameter, with twenty-four arms, each carrying a bucket 2.5 meters broad and 2.25 meters radial depth, working in a trough with a self-acting valve opening outward. There are eight large boilers, of which only six are used at a time, the others being held in reserve. There are two gangs of wheels, three in a gang, each set worked by an engine—that is, there are two engines in all. The lift is 1.3 meters with all six wheels, or 2 meters with four wheels. The engine cranks move pinions, making thirty-six revolutions per minute, which work into large cog-wheels keyed to the main shaft, giving the water wheels four revolutions. Capacity, 80 000 to 120 000 cubic meters per hour.

The draining machines for the city water of Amsterdam (that is, the water of the canals, etc.) have eight boilers, four engines, eight wheels, each of sixteen arms; buckets 3 meters wide; capacity, 100 000 cubic meters per hour; lift 1.2 meters with eight wheels, 2 meters with two (?) wheels, which last height, however, is never needed, because the head to be overcome never amounts to so much. There is a sluice by which the city water may be shut off from the North Sea Canal when necessary. Formerly there was direct communication with the Zuider Zee by a sluice. Now, since the construction of the Merwede Canal, resort must be had to other means. The canal itself could not be used as an intermediary, because of the great disturbance of its level that would ensue from the introduction of a vast quantity of drainage water after a rain for instance, or the withdrawal of an equally large quantity to freshen the city water, as is often necessary. Therefore, three great siphons have been sunk under the canal, giving the required communication. The siphons are of iron, square in section, and are supported only at the ends. They can be hoisted for cleaning or other purposes.

The "mill" at Halfweg has six wheels, arms 7 meters long, twenty-four in number, 2 meters broad, four large boilers. The engines make

* Beekman, op. cit., p. 116.

sixteen revolutions per minute, the wheels four. Capacity, 90 000 cubic meters per hour. Lift with all six wheels 1 meter, with four wheels said to be 1.5. Sluice valves, "tankard" pattern. The Spaarndam works have ten wheels, each with twenty arms; eight of the wheels have buckets 2 meters wide, two have them 2.5 meters. Two engines, four very large boilers, valves small double gates. There was no attendant there, hence no details could be learned as to capacity, etc.

The pumping apparatus of the Haarlem Lake polder is different from any other in the Netherlands, being the same that was originally used to pump out the lake. There are three pumping stations. The machinery of all is nearly similar. Briefly, it consists of a powerful Cornish engine, working several pumps. The machines are named the Leeghwater, Cruquius and Lynden, of which the Leeghwater was the first constructed. There is a full description of it in "Appleton's Dictionary of Mechanics," article "Pump, Leeghwater Steam" (Vol. II, pp. 506–510). It has eleven pumps, each 63 inches in diameter, of which only nine are used at a time.* The Lynden and Cruquius machines have eight pumps of 73 inches in diameter, of which seven are used at once. The extreme lift is 17 feet.

During the months from April to August, when the evaporation exceeds the rainfall, it may be necessary to let the water from the bosom into the polder. This may often be done without special appliances, as, for instance, by opening the outlet valve by a crowbar. Sometimes there are sluices in the outlet valve. Sometimes there are special conduits, running outside of and around the mills, closed by sliding gates, which need only to be raised to admit the outer water. Sometimes there are inlet culverts or pipes, as at Haarlem Lake. If there be not sufficient water in the bosom, then more must be admitted from the outer water. The Rhineland district has three points of inletting, at Gouda, at Leidschendam and at Bodegraven. In 1868 there were admitted at these places 167 000 000 cubic meters. In nine years there were admitted, in the average, 49 000 000 cubic meters annually.†

The dikes of many of the older polders were constructed, not only to keep out the bosom water, but even the sea or river water in the event of a break in the main dikes. Such accidents used to occur quite frequently. While they work great injury to all alluvial lands, they are

* Statement of attendant at the Lynden pump.

† Beekman, "Nederland als Polderland," 117–118.

especially calamitous to deep polders, or droogmakeryen, as these cannot be drained naturally, but must be pumped out again. It is almost impracticable, however, to give great height to the levees of the South Holland polders, on account of their depth and the weakness of the underground. They are therefore usually built so as to project only 0.5 or 0.6 meter above the bosom water, after allowing for probable settling and shrinkage.*

The cross-sections of the polder levees are very variable, as might be expected. For high-lying polders they are insignificant, still more so for the division levees which sometimes separate large polders into two or more parts. Where the land inclosed, however, lies very deep and is extensive and vlauable, the levees are often larger than the average of river dikes, though not so high. These increased dimensions are partly due to the fact that the polder levees have to stand the pressure of a considerable head of water, not for a few days or a few weeks, but all the year round, without intermission. They are still more due to the poor quality of the material of which the levees are composed, which is mostly, from the nature of the situation, peat ground. Clay, of course, is scarce and valuable and lies very deep. Nevertheless, a good and tight levee may be made of peat. For this purpose it is put up in thin and even layers, thus avoiding excessive shrinkage. Such embankments are subject to the further danger of sloughing and sinking into the underground, accompanied by a rising or "bulging" of the bottom of the ring canal. This danger is met, as far as possible, by giving a great base to the embankment and leaving wide berms. Sometimes a *kleikist* or muck ditch is used, 2 to 2.5 meters wide, and extending, if possible, in depth into the clay stratum, or, if this cannot well be reached, at least 2.5 or 3 meters deep. The ditch is filled with good clay, well tamped, and brought to a height of 0.2 to 0.3 above the ground. Plate LXIX shows a typical section from Beekman, of a polder levee, with its ditch on the inside and its ring canal on the outside, used for the purpose of navigation, as is common. The flat slope is placed on the inside, as it would not be suitable for the side wall of a canal. The second figure shows the apparatus for draining. The Haarlem Lake levee is even stronger than the type represented. It appeared to have a land slope of about 10 to 1, with an immensely broad crown and a canal about 150 feet wide. Large vessels were upon it.

* Storm-Buysing, Waterbouwkunde, ii, 378.

PLATE LXIX.
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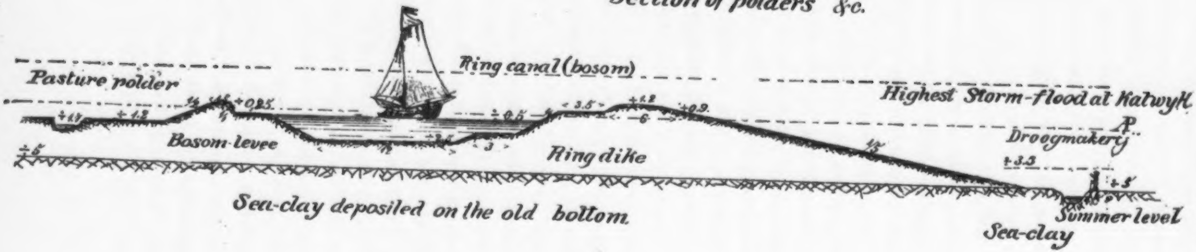
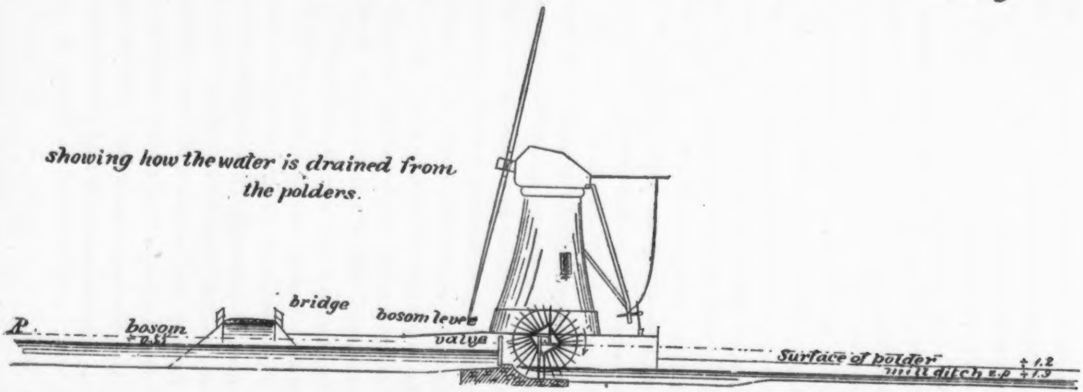
Section of polders &c.



showing how the water is drained from the polders.



The reclamation of Haarlem Lake was so remarkable an enterprise that it deserves a short notice. It is interesting to engineers in several particulars. Accurate records of its history are in existence and are preserved in print.* It appears, then, that in 1531 four lakes occupied the space which was afterward covered by Haarlem Lake. Their collective area was 21 530 acres. They lay in the low fen lands, and every storm cut away a part of their shores, until in 1591 they formed a single sheet of 26 390 acres, and had swallowed up the village of Vyfhuizen. In 1647 the area had increased to 36 110 acres, and two more villages had disappeared down the jaws of the "water wolf," as the people termed it. In 1740 the lake possessed a surface of 41 510 acres, in 1808 of 44 440 acres, and at the time of the reclamation, 1849, 45 500 acres. The loose turf displaced by the storms was either burnt for fuel or carried to the sea through the sluices at Spaarndam. Costly works were undertaken for the protection of the banks, but the district was not equal to the task. The State finally contributed to the undertaking, and such was felt to be the magnitude of the emergency that even distant Utrecht lent its aid. The sum thus appropriated was about $720 000. So great was the rejoicing that the town of Aalsmeer appointed an annual day of thanksgiving, which was kept till 1795.

The destruction of the banks, however, was not the only evil to be combated. By the effect of the wind on this large and continually increasing body of water, the surface on one side was frequently raised during storms to a dangerous extent. As early as 1639, Leeghwater, already mentioned, had demonstrated the practicability of draining the lake, and his work had gone through many editions. Other plans were suggested; but it was not until the present century, when the introduction of steam as a motor opened new possibilities, that the project began to be seriously canvassed, and it was finally given a new impulse by the storm of 1836, previously alluded to. A law was at length passed in 1839, opening a loan of eight million florins, and appointing a commission of management. First, however, provision must be made for the great diminution of reservoir surface which was about to take place. The lake was actually 85 per cent. of the whole bosom of the Rhineland. To compensate for this loss, the sluices at Katwyk were enlarged and new facilities provided for conducting water to them. Steam mills were erected at Spaarndam, Halfweg and Gouda. There was much difficulty in build-

* Beekman, De Strijd om het Bestaan, pp. 241–249.

ing the ring levee on the weak and treacherous, sometimes "half floating," soil, as it is described. After completion, the levee shrank and settled till it reached 4 feet below its original grade. It is about 17 miles in circumference. The pumps have been adverted to. When they were built they were among the wonders of the world, and it is doubtful whether they have been surpassed since. They worked more than three years (being stopped 210 days, on account of the bosom being too full). The quantity of water evacuated was more than 800 000 000 cubic meters, or say tons.*

The total cost was 13 920 000 florins, or say $5 500 000, of which nearly one-third went for interest; 42 200 acres were sold to individuals for $3 142 800, or nearly $80 per acre. At present, the polder does not present a very flourishing appearance. The soil after it was drained was found to be poor and sandy in places, the layer of clay being there thin or missing. It is laid out in straight lines and right angles, with the eternal double rows of trees along the roads. It seems there has been much difficulty in this extensive polder, in keeping the water to a level that is satisfactory to all—some of the lands lying much higher than others. This has caused a part of the polder to be separated from the rest by a subordinate levee.

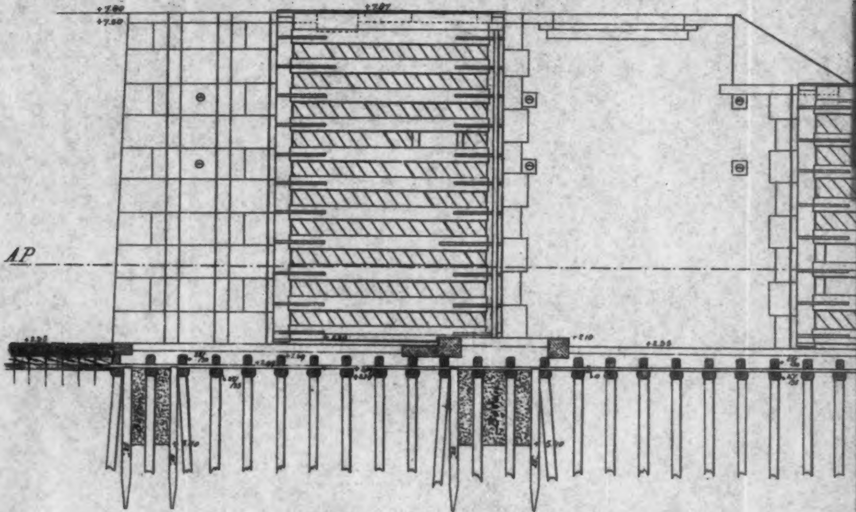
The process of draining into the sea or the rivers in the natural way is performed through the medium of sluices or locks. Where the passage is used for purposes of navigation, the latter must of course be employed. Where this necessity does not exist, a simpler form of sluice is used, called by the Dutch an "outwatering sluice." These devices are simple in principle, consisting merely of a masonry culvert, usually brick, with folding or sliding gates; but however simple, they demand much care and skill in construction, owing to the fact that they are placed in earthen dams with a considerable head against them, and on earthen foundations, and sometimes with earth of the worst quality in each situation.

Culverts even of the ordinary dimensions are almost always placed on piles and with the same precautions that are used with lock floors. Piles are the grand resource in Holland and this the more that they have a very long life in that soil. In Belgium it is said that in many situations they decay very rapidly.† Piles in small works are usually driven

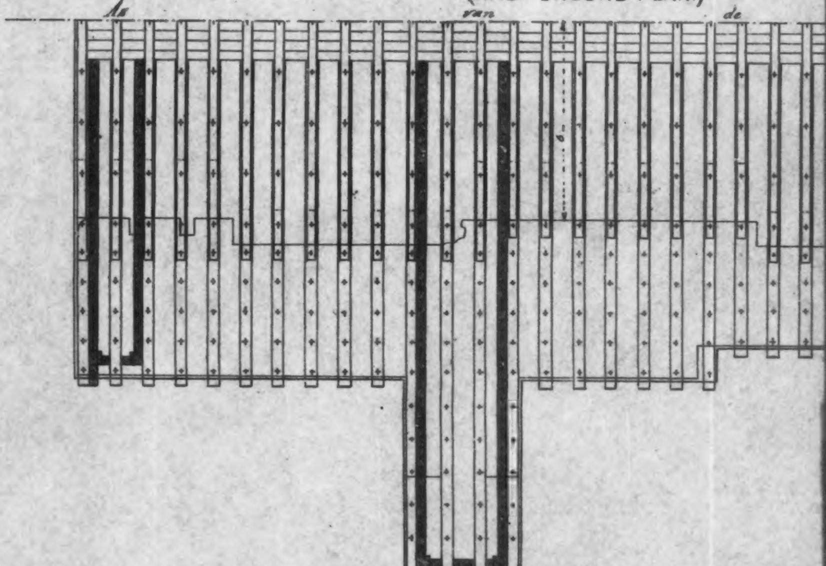
* A cubic meter weighs about 2 205 pounds.

† Gaudard on Foundations, p. 12 (Van Nostrand's Science Series).

SECTION OF THE LOCK AT VREESWICK.



(HALF GROUND PLAN.)



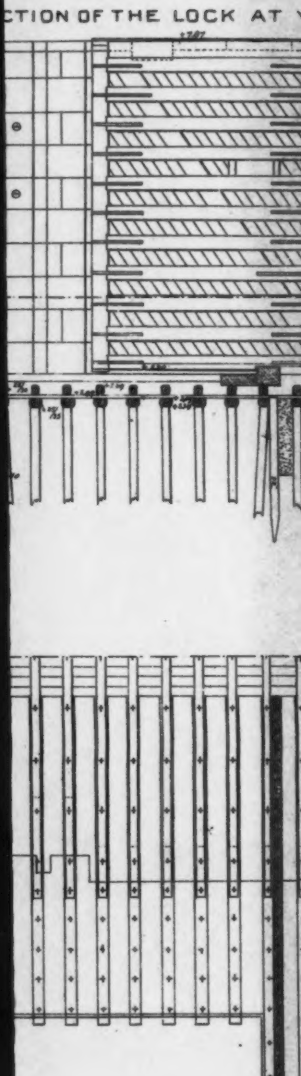
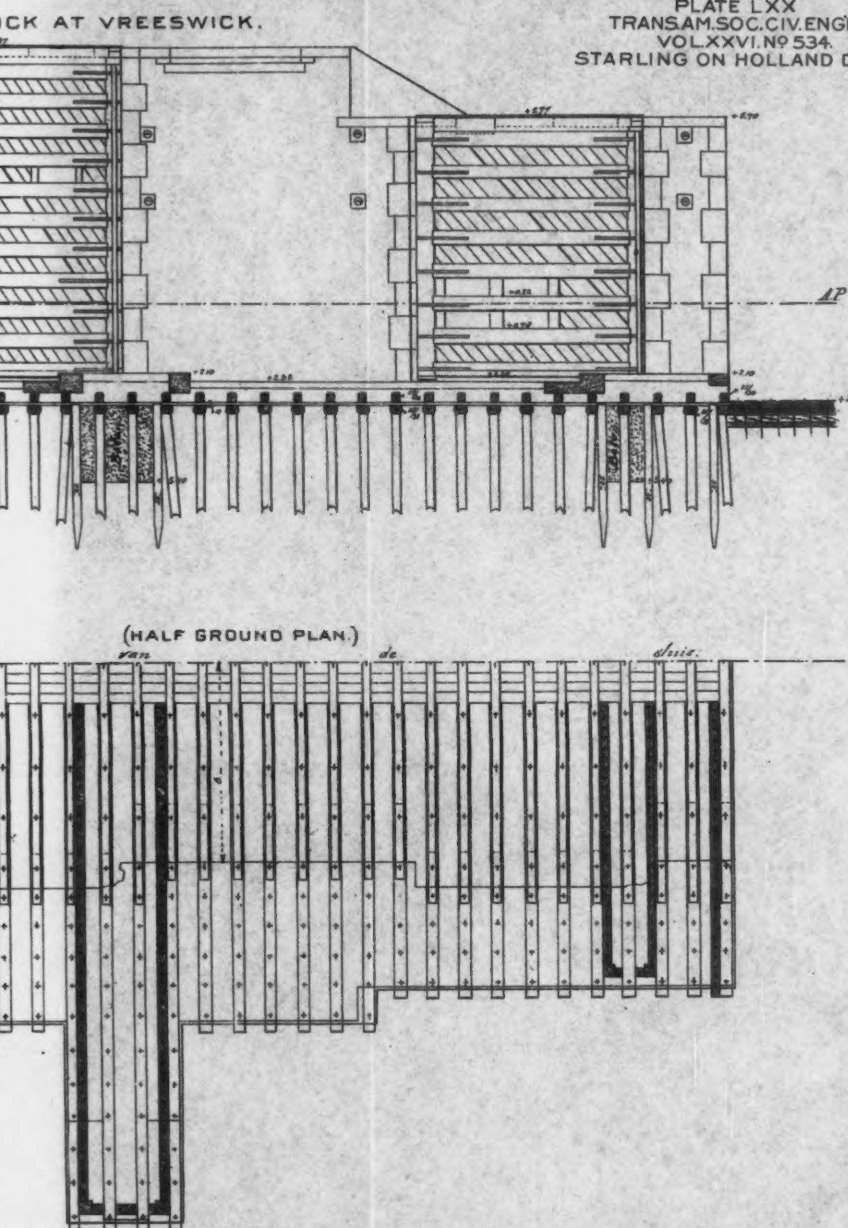

CTION OF THE LOCK AT

PLATE LXX
TRANS.AM.SOC.CIV.ENGRS.
VOL.XXVI. Nº 534.
STARLING ON HOLLAND DIKES.



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by a hand engine, with a hammer varying in weight according to the number of men employed. Ordinarily the proportion is 15 kilograms or say 33 pounds per man. Generally about ten men work at once. The frame is a three-stick sheers, of which two sticks lie in a vertical plane. There is a tie across the two at the top, from which are suspended two sheaves, one for the pile and one for the hammer. To the tie are fixed two rings through which pass the leads—long, round, slender poles, perhaps 50 or 60 feet in length. When the leads are to be moved, they are worked by one of the sheaves as if they were piles. The same arrangement was seen used with steam power with a hammer of 450 kilos.

In laying the floors of locks or culverts, the caps are secured to the piles by mortises and tenons, the tenons being wedged so as to make a dovetail joint.* The stringers are placed and secured in the ordinary way, the caps being let into them about 2 inches. The best dry clay is then filled in between the caps and thoroughly tamped, after which the lower floor or pine floor of 3 or 4-inch plank is laid with all possible care, calked and pitched. Previously to this four or more rows of "dam plank" have been driven, being sheet piles of pine or fir, 3 to 4 inches thick, joined to one another by tongues and grooves and extending into the ground from 10 to 16 feet, their mission being of course to cut off leakage under the floor. In some important works, as in the Vreeswyk locks of the new Merwede Canal, the spaces between adjacent rows of dam plank are filled with concrete—see Plate LXX. Over the pine floor is placed a third tier of timbers or cross-pieces, perpendicular to the stringers and parallel to and exactly over the caps, projecting 1.5 or 2 feet at each end and built into the side walls. They are fastened as strongly as possible through the floor to the caps, so as to form, as nearly as may be, one whole with them. If the floor of the lock is to be built of masonry, the woodwork is completed with the cross-pieces. Otherwise the spaces between the cross-pieces are built up with carefully laid masonry, consisting of hard burned brick (*klinkers*) laid in cement and covered with a layer of the same. On this is placed the upper or oaken floor, calked and pitched.

The particular duty of the tier of cross-pieces is to protect the floor of the lock or culvert from the upward pressure of the water. Even after every precaution is taken to prevent infiltration, by dam planks

* Algemeene Voorschriften, § 200.

and the like, it will often happen that there is a very dangerous quantity of leak water in the soil, which exerts a hydrostatic (or rather a hydraulic) pressure on the floor. This is the same influence that has been alluded to as forming one of the principal elements of danger to dikes built on bad soil, and it is the more threatening to locks or culverts on account of the comparatively narrow base which economy prescribes for such structures, whereby the pressure of the external water is not much diminished by friction. Accordingly the Dutch engineers,* in calculating the amount of the *oppersing* as they call it (up-pressing or upward thrust), assume that the pressure is purely static and equal to that theoretically due to the head. The resistance opposed to this force is composed of the strength of the cross-pieces and caps, held down as they are by the weight of the side walls and the frictional resistance of the piles to being drawn out of the ground (the floor being dovetailed to the piles by means of the caps). Particular stress is laid upon this by the Dutch, and attention is specially called to it because, it is believed, some American engineers are disposed to underrate the effect of upward thrust from soil water. It will no doubt appear that the estimate of its power by the Dutch engineers is excessive; but it must be remembered that their perhaps over-great precautions are not entirely due to theoretical considerations, but are no doubt partly the result of the experience of repeated failures. Even now, it is said, there is a bad leak in the floor of one of the great locks at Ymuiden, which has not been stopped. In place of the upper tier of cross-pieces, if the floor is to be of masonry, it may be built in the shape of an invert, but the piles, caps, stringers and pine floor are usually retained. Mr. Kemper informed the author that a departure was made from this method in the new locks now under construction at Ymuiden. They are founded on concrete alone—no piles.

Two principal types of outwatering sluice are described as being in use. In one, the dike is cut through nearly to the crown on each side, and vertical front and back walls of masonry with wing walls of the same provided. In this case, the culvert proper is only about the crown width. In the other type, the dike is cut down only partly up the slopes, making a longer culvert, but lower front walls and shorter wings. The latter is the type of which the most instances were seen. It would seem to be far preferable in bad soil and is the prevalent pattern in Zeeland.

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* Storm-Buysing, Waterbouwkunde, ii, 231-237.

Gates are either sliding, in grooves, raised and lowered by a rack and pinion or screw, or they are lock gates, arranged in pairs. They may be at the end or in the middle. In the latter case, they must be made so as to act automatically, and close by the mere pressure of the water. In most sluices there are also one or more sets of grooves to receive stop planks, if necessary, and windlasses are provided, in the larger sluices, for raising and lowering them. Stop planks are of very general use in the sluices and locks of the Netherlands. They are frequently placed in pairs, and the space between them filled with well-tamped clay. The larger outwatering sluices are elaborate structures, and indeed some of them are monuments of excellent engineering. The largest and most celebrated of them all is the great sluice or aggregation of sluices at Katwyk, to which allusion has frequently been made. This massive work, though built so long ago (in 1807), is said to be the finest of the kind in Europe, and the engineer, Conrad, has a monument in the Cathedral at Haarlem.

The Katwyk sluice belongs to the category of "flushing sluices" (*spuisluizen* as the Dutch call them), in which the inner water is allowed to accumulate to a considerable head, and is then discharged suddenly for the purpose of sweeping away aggregations of silt. In case the level of the inner water is not sufficient to accomplish this object, the outer water is admitted, at time of flood, into a large chamber, which is then opened near ebb. At Katwyk, the chamber is the space included between the outer and innermost sluices (there are three altogether), of 1 500 meters in length. See the plan, Fig. 7.* There are five open-

FIG. 7.

ings in the outer sluice, each closed by a sliding gate, raised and lowered by a winch and chain, the latter passing over a sheave, with a counterpoise. Besides this, there are two grooves at each end of the sluice to receive stop planks for repairs or emergencies. The outer water is

* From Storm-Buysing.

admitted only through the middle opening, by a special appliance, designed to keep out the greater portion of the silt suspended in the sea water. For this purpose the sliding gate of the middle opening is divided horizontally into two, the upper one alone being raised for the admission of the outer water. When the chamber is high enough, the gate is closed and the water retained until the tide has run out sufficiently, when all the sluices are opened. They usually remain open five or six hours. The head under which they work is great enough to sweep away the masses of sand thrown up by the sea. Of course an elaborate spillway is required. The second or middle sluice, which lies 500 meters from the outer, is sufficient to keep out the greatest external flood, and is therefore an additional security against accident from such a source. It was originally intended also as a flushing sluice in case the canal itself became silted up within the outer sluice. It was found, however, that fears on this account were groundless, and the flushing gates were removed.* When Haarlem Lake was reclaimed, it was found necessary to enlarge the inner sluices; and in 1880 the powerful steam pumping plant previously mentioned was built.

It has already been said that the tops of the dikes, in almost all instances, are either paved or graveled, and used as roadways. If they are paved, it is always with brick, of the kind which the Dutch call *klinkers*, from the clear ring which they emit when knocked together. These are very hard burned brick, of medium or small size, obtained mostly from two sources, the Yssel of Holland and the Waal. The former are very small, yellow in color, and very hard. The material for them is gotten from the muddy bed of the Yssel, the deposits of which are admirably adapted for this purpose.† The chief depots for them are Gouda and Rotterdam. The Waal brick are considerably larger, nearly the size of one of our American bricks, and of a dark red color. They are more generally esteemed for road making. Yssel brick, however, are occasionally made Waal-size, as they term it. They are laid on a sand bed, by preference not less than 16 inches thick, on edge, with the longest side perpendicular to the axis of the dike. It was observed by a very intelligent engineer‡ that brick do not make a satisfactory road for heavy hauling, as they will not stand such hard use for more than two

* Storm-Buysing, ii, 210.
† Baedeker.
‡ Mr. Wisboom.

or three years, but they are excellent for ordinary traffic. The author saw some brick roads which were said to have been built in the time of Napoleon. In Zeeland they prefer them to gravel, as the soil in these islands is soft and clayey, and the gravel is apt to sink.

The gravel roads, however, predominate by far, and constitute, perhaps, nine-tenths of the present highways. It may be remarked that good roads have not always been the rule in Holland. On the contrary, they are of comparatively recent origin, dating no further back than the era of Napoleon. Under his régime a great national road was built through Holland and Belgium and via Amiens to Paris, and in the reign of his brother, King Louis, the impulse thus given was vigorously followed. In fact, the Dutch people hail the memory of King Louis as the author of the present excellent system, under which the whole kingdom is traversed by admirable artificial ways. It is not to be supposed that the making of these roads is easy or cheap. The material does not lie close at hand, but must be transported from a considerable distance and handled repeatedly. It is true that water transportation is cheap and labor sufficient, but Holland has no great advantages in these regards over other alluvial regions. In other words, what the Dutch have done, the people of the Mississippi Valley may do, or any others who have the requisite energy and population. The gravel for the Dutch roads comes from three sources*—by dredging, from the upper Waal, above Tiel ; from the Maas, and from the hills of Limburg and elsewhere in the region of the gravel diluvium. The last is preferred (as similar qualities are also in America, for railroad ballast and for streets) from the fact that there is a matrix of earth surrounding and cementing the pebbles, and serving the same purpose of giving hardness, firmness and tenacity when they are put into a road. The gravel is run through one or more screens and the different sizes separated, the larger being used for the lower layer and the smaller for the upper.

The General Regulations† prescribe that first a suitable bed shall be prepared, of the proper consistency and shape, with a convex or cylindrical upper surface. On this shall be placed a layer of refuse brick, laid flat and regular, the joints filled with sand or mortar refuse. Next comes a layer of broken brick and then the gravel. According to par-

* Mr. Leemans.

† Algemeene Voorschriften, §§ 296–302.

ticular specifications,* the gravel is to be placed in three layers, altogether 6 inches thick. Each layer is sprinkled with a layer of clay 2 centimeters thick, or say 0.8 inch, well rammed and rolled. As to this particular, Mr. Wisboom stated that there was a difference of opinion among engineers, some maintaining that the admixture of clay was detrimental, and that gravel alone was preferable.

A subject of great interest to river engineers is the experience of the Dutch with outlets. It is known that this system had a faithful trial on the large rivers of Holland, and the author made inquiries of all the engineers he met as to the results of the experiment. It was found that at one time it had been the fashion, and that some remains of it were still in existence. The branch of the Rhine called the "Gueldres Yssel" gives a somewhat shorter route to the sea level than the Lek or the Waal, and the lands which lie along its course are high, not subject to serious injury by inundation, and capable of being drained, in case of such a misfortune, by natural means. The Yssel was not originally, as it appears, an arm of the Rhine at all, but was a separate river, of which the upper part still exists under the name of the Old Yssel. The connection with the Rhine arose either from the cutting of a canal in the Roman times by Drusus, or by the enlargement by the latter of a channel which had already begun to cut itself out in time of overflow.† The Yssel, at its mean stage, carries off one-ninth of the whole discharge of the Rhine, and in time of flood a still larger proportion. It was found that this gave a great relief to the dangerous and much threatened Lek country, and it was very natural to wish to make this relief still greater and more certain by providing means whereby a still more considerable part of the high water discharge could be transferred to the shorter and less dangerous stream.

In Holland, as in America, after every serious disaster, or even a season of great alarm and expense, a variety of counsels have been offered for the prevention of future damages, and the drawbacks of the dike system are made the subject of vigorous attack. These drawbacks are the expense, always increasing as the dikes are made higher and heavier, and the ever-present possibility of breaks, with their attendant consequences of loss of property or even of life, which also become more formidable as the dikes are given a greater height. To these real dis-

* Specifications for the graveling of the Heerewaarden Dikes, August, 1888.

† Beekman, "Netherland als Polderland," p. 16.

advantages are generally added others which have no substantial foundation. The truth is, that communities, usually of limited extent and not superabundant resources, become appalled at the prospect of the millions to be spent in the attainment of a perfect dike system, which, like a mountain peak, seemed at the beginning to be easily within reach, but, after a long and toilsome progress, is still far off. Hence there is a continual temptation to try other methods, by way of experiment at least, and some of them look plausible enough to command the attention of intelligent people, and even of some among the profession of engineers. In the earlier part of the present century there appears to have prevailed in Holland a feeling of profound discouragement. The formidable danger of ice gorges had been present with unusually great frequency, and this seemed a peril against which even increased height and strength of dikes could not assure immunity. It was held, even by the majority of engineers, that "the dikes had corrupted the state of the land," and that, at least, the system had been resorted to prematurely, and before the country was prepared for it and in the proper condition; that is, it may be supposed, before the flood plain had attained its proper development, and the banks had been built up to a sufficient height.* A commission of engineers was appointed in 1821, and in 1827 their report was published, recommending, among other things, an extensive series of outlets. The programme encountered strong opposition, and was never carried out further than to widen some of the existing outlets on the Maas. There were already several of these weirs, and they were allowed to remain until a very late date.

The principal outlet was about the upper mouth or point of departure of the Yssel of Gelderland, already mentioned as affording unusual facilities for the trial of such a scheme. In 1809 an *overlaat* was put in at this point, about 2 miles long. As the Yssel itself at this place was not considered large enough to carry the additional discharge, other overlaten were made in its banks, to allow the overflow water either to return to the stream lower down, at some more favorable point, or to seek another exit into the Zuider Zee. This series of weirs has now been suppressed, and the only remnant of the system is one of those which formerly existed on the Maas—namely, the Beers overlaat, formerly alluded to, which deserves a notice in connection with the interesting work for giving a new mouth to the River Maas.

* Storm-Buysing, ii, 56.

It has already been said that the Maas is not diked for its whole length. A few years ago there were three openings in the line—two on the southern bank and one on the northern. The former were called respectively the Beers and Bokhoven overlaten, the latter the Heerewaarden overlaat. From the two former the Maas water flowed over its banks and inundated its own valley. The last named is situated at the point where the Waal and the Maas approach one another so closely, and as the Waal is equally undiked here, it allows the water of the greater river to overflow into the less. Therefore, so far as the Maas is concerned, the Heerewaarden overlaat is not an outlet at all, but rather an inlet.*

Of the weirs on the southern bank, the higher is situated near the very beginning of the dike system, about 1 mile below the point where the Maas is crossed by the railway from Venlo to Nymegen, just above the town of Grave, and near the village of Beers. Here is a gap in the dike about a mile and a half in length. This is not left entirely open, but is partially closed by a "summer levee," of which the greater part, however, is not permanent, but must be removed during the winter, to be restored after the flood. The remaining portion is constructed for the special purpose of allowing the water to run over it. Collectively, the gap is called the Beersche overlaat, and the water which pours over it in time of flood is called the Beersche Maas.

The term overlaat is used to designate any kind of outlet or waste weir. It is rendered into French by the word *déversoir*. It is applied to several very dissimilar constructions, not only to open or undiked lands, but to sluices in the main dikes, designed, in case of necessity, to let out inundation water, and to low stretches in the same dikes, topped or surmounted by a small and easily removed supplementary levee, of which we have seen several examples. The author did not see the Beers outlet, but he saw the one at Heerewaarden, which is said to be very similar. It consisted partly of merely low and flat dike, and partly of *stortebed* or spillway. The latter was carefully faced with basalt blocks, with a moderate outside (Waal-side) slope, 2.5 to 1, and a long slope on the Maas side, 10 to 1. The crown was given a rounded form. It was 2 meters broad.† The specifications for these works‡ provide that the

* An overflow of the Maas into the Waal, of any consequence, has never occurred.

† See Plate LXIV.

‡ Waterstaat. Beteugeling der Heerewaardensche Overlaten. Dienst 1888. Bestek en Voorwaarden, etc. No. 188. Aug. 29, 1888.

embankments shall be built entirely of clay, the borrow-pits to be distant not less than 50 meters on the Maas side, and covered with a straw mat, brick rubble and basalt in succession. The Bokhoven overlaat is merely undiked land. The Baardwyk overlaat, of which hereafter, is protected by what has been designated as *rysbeslag*, that is, by a brush dressing covered by a layer of rubble, stone or brick.

At a stage of about 4.5 feet below the grade of the Maas dikes, the water begins to pour over the Beers outlet, or, as the technical phrase is, "the outlet works." It fills the low space between the southern Maas dike and the heath lands of North Brabant (a distance of 2 or 3 miles), and soon reaches the important city of 's Hertogenbosch, or Bois-le-Duc, the capital of the province, where it encounters the small river Dieze, running nearly perpendicular to the course of the overflow water, and diked on both sides. There are two sluices and some low places (overlaten again) in the eastern Dieze dike, and through them the inundation water finds its exit into the Maas again at the mouth of the Dieze at Crèvecœur. A portion, however, of the overflow may pass to the south of Bois-le-Duc (depending on the height of the flood, etc.). Now, from Crèvecœur to Bokhoven, half a mile or so (800 meters), the Maas has no dikes. Through this gap the excess of overflow water may enter the Maas, provided the latter be low enough. If the Maas be at all high, this return flow is not possible. On the contrary, the very reverse operation may take place, and the Bokhoven overlaat may aggravate the overflow. This is an incident of frequent occurrence, especially from high water in the Waal, which river, as has been seen, at high stages, has had, until recently, direct communication with the Maas over the Heerewaarden overlaat, and has still, at the mouth of the Maas at Woudrichem, only 15 miles below Bokhoven.

Now, the Waal is a much larger river than the Maas. In fact, it is three times as great. The communication between the two streams, then, is entirely to the disadvantage of the Maas, that is, the latter never seriously affects the Waal, while the Waal may produce formidable floods in the smaller river. Both by direct flood, then, at Heerewaarden and by back water from Woudrichem, the Maas may be so raised at Bokhoven as to pour a considerable volume over the bank. This finds its way rather deviously between diked lands through the bottom called the Langestraat, corresponding, in the lower part of its course, to the valley of the Old Maasje (little

Maas), an old, abandoned and deteriorated bed of the Maas, to the Hollandsch Diep, and thence to the sea at Hellevoetsluis. The combined volume of the overflow may be so considerable as to threaten the dikes which border the zone of inundation. Breaks not unfrequently occur and produce disastrous overflows. Mr. Wisboom pointed out the locality of a crevasse which occurred in 1880, near Nieuwkuyck. The entrance or sill of the Langestraat forms a narrow pass which is partially closed by the Baardwyk overlaat above alluded to. This outlet is large enough to give passage to the whole volume of the overflow which enters via Bokhoven.* It is a kilometer wide, say three-fifths of a mile.

By this system it will appear that a portion of the flood water of the Maas is diverted from the main stream and allowed to flow by a side channel until it either regains the parent river or enters the sea, according to circumstances. The overflowed country is mostly not directly inhabited, that is, there are no houses or dwellings in it, except in the City of Bois-le-Duc, which is surrounded by the inundation water, but raised above it.† It is not abandoned either, but turned into grazing land for the most part, though occasionally grain and other crops are planted, when the overflow goes down in time, that is, by April. This it would almost always do, did the inundation proceed from the Maas alone. But the Waal sometimes is in flood in May and June, and thus the relief of the polders of the Maas is delayed to an extent which may be fatal. Otherwise the overflow is not regarded as a calamity. The ground between the Maas and the uplands is not of the best quality, and needs the fertilizing influence of the floods. Nevertheless, the polder lands about Heusden, which are inclosed by dikes, are worth twice as much as those included in the overflowed tract, the former being valued at $800 per acre. The overlaten themselves are closed, as soon as their function is ended, every year, by summer levees, which, however, must be demolished before winter.

The evils of this situation are numerous. First, as to the Waal itself. The flow through the overlaten causes an abrupt change of direction of the current and a loss of volume, hence diminishes the velocity of the

* Notice sur les Travaux de Séparation de la Meuse et du Wahal. (Par C. Schnebbelie, Ingénieur-en-Chef du Waterstaat.) Bois-le-Duc, 1889. An abridgment of this paper is contained in the volume entitled "Les Voies de Navigation dans le Royaume des Pays-Bas," of which mention has been made.

† Mr. Wisboom says that he has skated all around the city.

main stream, brings about deposition of silt, a rise of the bottom and a shallowing of the water, and therefore promotes the formation of ice gorges in the Waal, the evil of all most dreaded in time of flood, as endangering the dikes above it. For the Maas it is equally disastrous. The subtraction of one-sixth of the high-water discharge of the Waal through the Heerewaarden outlet would add one-half to the contents of the Maas. Even though the Waal be not high enough to discharge any considerable quantity over its banks, yet it can "back up" from Woudrichem, and thus prevent the outflow of the Maas water, facilitate ice gorges, prevent their dissolution, and obstruct the drainage of the low lands. Hence the bold project of separating the two rivers entirely, and giving the Maas a new mouth. This scheme involves the closing of the Heerewaarden overlaat, the damming of the Maas just above its junction with the Waal, and the construction of a new bed, some 21 miles in length (inclusive of the channel called the Amer, which, with improvements, will form a part of the new Maas),* and large enough to pass the high-water discharge of the river. The overlaten at Beers and Bokhoven are left to be closed by the local authorities, should they choose to do so. The affair is not regarded as of national importance. It is Mr. Schnebbelie's opinion that they will be closed. The law authorizing the execution of the project was passed in 1882. The necessary act for the expropriation of lands was passed in 1885, and the work was begun in 1886.

The closing of the Heerewaarden outlet was not designed to take place suddenly, but by degrees, so that the rivers might have time to accommodate themselves to their altered regimen. Consequently, the work there has consisted of successive raisings and enlargements of the dikes and overlaten, which are still in progress. The canal of Sint Andries, near Heerewaarden, unites the two rivers for navigable purposes, and the raising of the locks is a part of the project. This is being done to full grade, but the last enlargement of the embankments brings them, the author thinks, only within 0.8 meter of that standard. There are to be two dams across the Maas—one at Neer-Andel, about 2 miles above its confluence with the Waal at Woudrichem, the other at Slyk-Well, just below the upper mouth of the new river, and forming a prolongation of the dike which constitutes its northern bank. Both are connected with

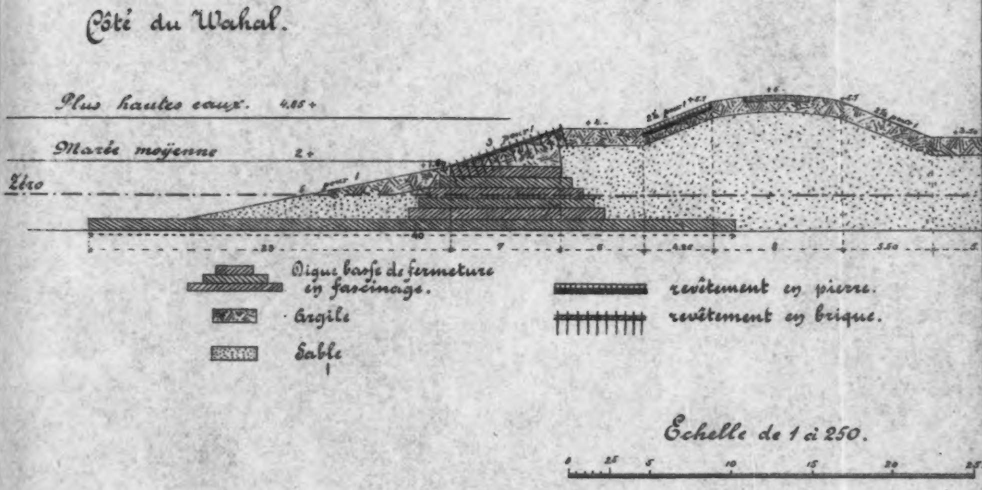
* The part which is to be actually constructed out and out, is about 13 miles. The bed of the old Maasje will also be used for a short distance, but it will have to be tripled in volume.

the systems of dikes on either side of the river. There will be sluices in the dams for the benefit of navigation.

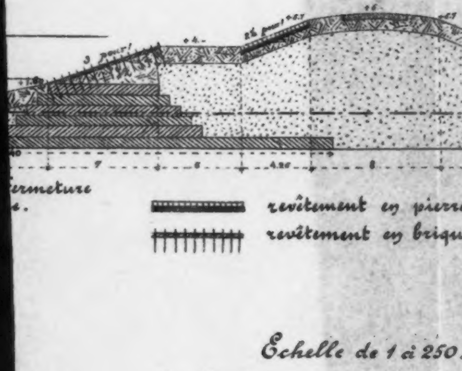
The project for the dams, as shown in the figure (Plate LXXI), which is from a tracing kindly given the author by Mr. Schnebbelie, consists simply of an earthen embankment, which will be constructed after closing the river by a low dam of fascine work (zinkstukken). Zinkstukken (sink pieces) are fabrics of fine brush, very much after the fashion of the "mattresses" so familiar to engineers on the Mississippi, but much smaller, of much finer material and made more compactly and with more care. They are of extensive use in river-works, and probably furnished the model for our own mattresses, with such modifications as adapted them to American use. The brush is the same that is ordinarily seen in the market in Holland, as it has already been described. To make a zinkstuk a grillage of fascine work is first laid, upon which two or more layers of brush are placed, and then the work is completed by another grillage, laid exactly over the first and drawn tightly to it. Upon the mattress thus finished a series of square pens is built out of brush, to hold the stone or other ballast which is to sink the mat.* The grillages are each composed of long fascines or saucissons, made, or, as they express it, spun, continuously and without joints to the required length, which may be 50 meters or more. They are required to be built of Holland brush, with the tops on, and must be 5 inches in diameter. Unless otherwise ordered, they are to be three feet apart from center to center. The bottom layer is to be placed in the direction in which the greatest strain is expected, whether this be lengthwise or transverse. Upon this the second layer is placed crosswise, the two layers being firmly bound together by withes and tarred rope, the latter being used at the ends and at every alternate joint, and having long projecting ends secured to upright temporary stakes. Upon the grillage is laid the brush in two or three layers, as the case may be, each layer being placed crosswise to the preceding. The thickness is 12 inches in the one event and 17 in the other. The brush is laid in bundles, as delivered, close and even. The top grillage is now placed, one layer at a time, as a cap to the work, the crossings of the two layers being vertically over those of the bottom grillage, as indicated by the temporary stakes above mentioned. The two grillages are then firmly drawn one to the other by the projecting ropes, which have been detached from the stakes, and the latter withdrawn.

* Algemeene Voorschriften, §§ 99–144.

Avant-projet de la digue de séparation
entre la Meuse et le Wahal
près de Neer-Andel.



Avant-projet de la digue de sépa
entre la Meuse et le Wah
pres de Neer-Andel -



…rmeture
…e.

revêtement en pierre

revêtement en briqu

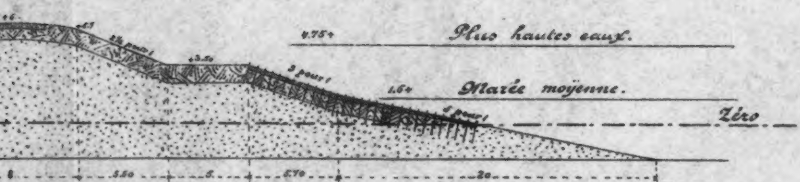
Echelle de 1 à 250.

0 2.5 5 10 15

PLATE LXXI
TRANS.AM.SOC.CIV.ENG'RS.
VOL.XXVI.Nº 534.
STARLING ON HOLLAND DIKES.

e de séparation
le Wahal
ndel -

Côté de la Meuse.



t en pierre.
t en brique.

le 1 à 250.

15 20 25M

The mattress thus constructed is prepared for the reception of the ballast by driving strong stakes, about 4 feet long, into it, and interweaving about them flexible twigs, forming a continuous low wattling in each direction, that is, lengthwise and crosswise. Thus will be presented a network of pens, which should be about 6 feet square each. In these is placed sufficient ballast (stone or brick) to give bare flotation to the mat. The latter is then sunk at once by rapidly and systematically throwing on more ballast. The last details of the process are almost identical with those pursued on the Mississippi, but are much simpler and easier on account of the small size of the mats and the slower current. The widest mat of the Neer-Andel dam (that at Slyk-Well is precisely similar) is 40 meters wide, the others being from 12.5 to 7. The thickness seems to be about 0.75 meter, or say 30 inches. The mattresses of the Mississippi work are frequently 100 meters or more wide and 300 meters long, and are sometimes sunk in a current of 2 meters per second. The fascine work will be built only to the height of mean tide in the Waal. Behind this, on the Maas side, the earthen dam will then be constructed.

The building of these enormous embankments in the bed of active or past streams may be supposed to be often attended with great difficulty, and such is indeed the case when the bed is composed of or underlaid by soft and compressible material. The trouble is comparatively small when the embankment is merely for a highway or railway. Then resort may be had to fascine-work or similar devices. But when the earthwork is intended to withstand the pressure of a considerable head of water, such means are frequently or generally of doubtful utility, or are even positively dangerous, as tending to permit destructive leakage under the bank. Under these circumstances it has been a puzzle to levee engineers what was the safest and most economical course to pursue, and most of them have fallen back on the simple rule of earth and more earth. The Dutch engineers have had their full share of these troubles and they seem to have come to very much the same conclusion. Of course, the principal difficulty with soft soils is that the embankment keeps sinking and displacing the ground which serves as its foundation, the latter in the meantime forcing up the surface of the surrounding land, and this sinking may be of indefinite and unascertainable extent. It is true that there are formulas by which we may calculate it to a nicety if we only know the angle of repose of the soil. That, however,

is generally the very thing we do not know. Experiments made to ascertain it during the period of construction may be very misleading—as the soil may then be in a very different condition from that which it will assume at the time of danger. Practically, we find that an embankment may continue to sink until it has very nearly displaced its own weight before it comes to an equilibrium, and that on attempting to complete the work by adding more earth the process is likely to recommence. Furthermore, this will very possibly take place at the most inconvenient time, that is, at the time of flood, when the water stands high against the dike or dam and the soil is thoroughly permeated and softened. Consequently, various devices have been tried in the way of piles, grillages, fascines and the like, with the result that they have partially stopped the settling at great expense and sometimes at the risk of losing the dike.

Mr. Kemper, one of the engineers of the new Amsterdam-Merwede Canal, exhibited a number of very interesting profiles and sections, exhibiting the displacements that had taken place at various points of his line—sometimes amounting to a very considerable fraction of the whole contents of the bank. Mr. Wisboom, previously mentioned, assured the author that he had known instances where it had equaled twice the contents of the embankment—in other words, the work had to be built thrice before it reached its final equilibrium. Mr. Kemper said that in building some of the locks about Amsterdam, they had to throw in sand in vast quantities to displace the mud and peat, and then drive their piles into the sand. At Vreeswyk, on the Lek, in one instance, they found it cheaper and more satisfactory to dig away the peat altogether and replace it with sand. They consider river sand to be quite good soil, at least in comparison with peat. Mr. Kemper kindly had made a copy of some of the borings at Amsterdam (as well as those at Vreeswyk, previously given). They appear on the next page. *Derrie* is very similar to peat, but found in a little different situation.

In the earthen dams lately built, the practice then has been, so far as could be learned, to rely almost entirely on earth, which is usually sand. The old books recommend *zinkstukken* or other foundations, and they are still used to some extent in desperate cases. The great dam across the Y at Schellingwoude has a single layer of *zinkstukken* under its center, and several under the foot of each slope. They are best adapted to such cases as this, where the bottom is very soft; where


A.P.
2.25
Derrie with traces of clay
6.45
Clay with a few shells.
7.15
Clay with sand
7.82
Sand with Clay.
9.00
Clay with shells.
10.12
Clay with peat.
11.12
Clay with shells.
12.37
Peat.
12.65
Sand with peat.
13.30
Sand with clay.
15.35
Sand with a little clay and some peat
19.55
Sand with shells and gravel.
24.45
2.40
Derrie.
6.
Clay.
7.
Clay with a little sand.
7.62
Sand with clay and a few shells.
8.67
Clay with shells.
9.80
Peat.
10.17
Clay with peat.
10.60
Clay with a few shells.
11.80
Peat.
12.07
Sand with a little peat.
12.92
Sand with clay.
15.25
Sand with clay and a little peat.
16.12
Sand with a little clay and gravel.
19.40
Sand with gravel and shells.
24.20
2.35
Derrie with traces of clay.
6.15
Clay with peat.
6.40
Clay with a little sand.
7.20
Sand with a few shells.
8.47
Clay with shells.
9.80
Clay with peat and a few shells.
11.17
Clay with a few shells.
12.35
Clay with peat.
12.52
Peat.
12.82
Sand with clay.
14.85
Sand with a little clay and a little peat.
16.50
Sand with some gravel.
17.55
Sand with a little peat and some gravel.
18.67
Sand with a little gravel and some shells
24.35
2.60
Derrie.
6.65
Clay.
7.50
Sand with a little clay.
8.12
Clay with a little peat.
9.44
Peat with some clay.
9.70
Clay.
11.
Clay with sand and shells.
11.55
Clay, sand and peat.
11.95
Sand with a little peat.
12.77
Sand with a few shells.
13.40
Clay with sand.
15.15
Clay and sand, with a little peat.
16.40
Clay with a little sand.
17.05
Coarse sand and clay.
17.75
Clay with a little sand.
18.80
Sand, clay and some peat.
19.40
Sand with a little clay.
20.73
Coarse sand with gravel.
21.42
Sand with very little clay and some shells.
24.45

there is water constantly standing on both sides, and the brush consequently kept covered, and where the difference of level between the internal and external water is not very great. Since the use of railroads for building banks, with steam excavators and dredges, sand is obtained so cheaply and in such large quantities that it is now the principal resource. It is a refuse product of dredging, which is largely carried on in the river improvements and canal works. The author saw it used in enormous volumes in the construction of the new Maas bed, where there is sometimes a good deal of peat encountered; and he saw there, too, a remarkable instance of the displacement of the latter by the sand of the new embankment. The peat had been forced to the top, as though by the superior specific gravity of the sand, and it lay, or, as it were, floated there, as an irregular, foul-looking, wet mass, not unlike a manure heap in appearance. This, he was told, is a very frequent phenomenon.

FIG. 8.

The fascine dams at Neer-Andel and Slyk-Well are merely auxiliary and are not essential parts of the new constructions. The most important, laborious and expensive part of the work is, of course, the construction of the new bed. The Maas is a river which discharges, at the highest water, some 2 700 cubic meters, or nearly 100 000 cubic feet per second. This is, perhaps, half of the high-water discharge of the Arkansas or White River. While no great matter for a living river, it is a pretty formidable flow to provide for artificially. The new river bed has an extreme width of 500 meters or 1 640 feet, and an extreme depth of nearly 8 meters, or about 26 feet. It is built partly in excavation and partly in embankment. Extending entirely to the sea, it undergoes a change of condition as it progresses downward from the fluvial part of the Maas, and the bed must be conformed to this change. The Maas at Slyk-Well, like other rivers, has a considerable range or oscillation, namely, about 17 feet. This oscillation depends almost entirely upon the supply of water from above. It has therefore its high-water bed and its low-water bed. The water-level in the former case extends nearly to the top of the dikes. In the latter it is far below the level

of the natural surface of the ground. The following, then, is a typical section of such a river:

FIG. 9.

Now, at the mouth, where it discharges into the sea or the estuary, there is no such condition. There are high waters and low waters, but they are dependent on the tides and not on freshets. The oscillations are daily and not annual or of long period. In short, the river has undergone a change, from the fluvial to the maritime regimen, and instead of two beds, one for summer and one for winter, we now have one only. In designing the new bed for the Maas, the engineers have had due regard to this condition. The low-water bed, in their project, keeps on increasing from the upper to the lower mouth. At the origin, the width of the "minor bed" is 170 meters. Eleven kilometers below it is 210 meters. At 22 kilometers, it is 265 meters. At 25, it is 315 meters. At the mouth, it is 495, or coincides substantially with the high-water bed. Not all of the "new river" is included between dikes. These extend for about 22 kilometers, or 13.6 miles, after which they cease, the new bed then using the antiquated channel of the Old Maasje to the estuary called the Amer, through which the stream flows into the Hollandsch Diep. The bed of the Old Maasje is only one-third large enough to accommodate the discharge of the new river, so it must be dredged and enlarged. The Amer is sometimes too wide, sometimes too narrow, sometimes too shallow, so it must be "regularized" by contraction, by widening or deepening, as the case may be. The bottom will have a slope of about 0.08 in 1 000, or about 0.42 foot to the mile.

The summer bed is made by excavation, the winter bed by embankment. As the quantity of material furnished by the former process is greatly in excess of the requirements for ordinary dikes, it follows that the enormous banks which are being thrown up are not, to use Mr. Schnebbelie's language, dikes properly so called, but partake of the nature of spoil banks. As has been before stated, for one-third of the distance the dikes have muck ditches under them. They are being constructed entirely by steam trams, standard gauge, with large iron ditching cars which hold 7 to 8 cubic meters each. The cars are filled by steam excavators. When the author saw the work they were excavating

the muck ditch by steam dredges. The trace of the new bed consists of several gentle curves, which change direction to the right and left alternately. The slopes of the summer bed are regulated according to these changes so as to conform to the practice of Nature, the steeper slope being on the concave bank. On this side the inclination is 5 to 1, on the other 10 to 1. The dikes have a slope of 2 or 2.5 on the land side and 5 to 1 on the water side. The crown varies from 10 to 114 meters—say 33 to 374 feet. The berm is mostly 15 meters. The summer bed commonly lies close to one of the dikes, northern or southern, leaving a wide interval between its bank and the toe of the other dike. It is intended to use this interval as pasture land, protecting it from small summer freshets by a summer levee on the margin of the low water bed. This adjunct, by the way, is extremely common, and, indeed, universal, where the foreshores are wide, on all the rivers. Outside of the dikes again are canals, intended to receive the drainage of the polders adjoining the new river, which formerly emptied into the Old Maasje. These canals will discharge into the new river by sluices, or, if necessary, will be drained by steam.

The cost of this novel though not unprecedented enterprise is estimated by Mr. Schnebbelie at 32 000 000 francs, or something over $6 000 000. This includes rights of way and everything except the closing of the Heerewaarden overlaten and a bridge at Heusden. Of this sum the Province of North Brabant contributes $200 000 and the polders interested $400 000. The rest of the expense is borne by the State. Of course great consequences must be expected to justify such an outlay. The ends designed to be attained are: *

First, by closing the Heerewaarden outlets the principal cause of ice gorges will be removed. Second, by the exclusion of the Waal water and by the greater slope given to the lower Maas there will result such a depression of the water surface, that even after the suppression of the outlets at Beers and Bokhoven, the Maas will never attain its former heights. Thus the dikes will no longer be menaced. Furthermore, the lands adjacent to the river may be drained. It is not believed that the Waal dikes will have to be raised in consequence of the closure of the Heerewaarden overlaten.†

It is very interesting to the American engineer, especially to those

* Travaux Séparation de la Meuse et du Wahal.

† Beekman, "Nederland als Polderland," p. 23.

engaged in the Mississippi service, to see what results Mr. Schnebbelie looks for and how high up stream the influence of these changes is expected to extend. It will be seen that his claims are very moderate:

Distances above origin of new river.	Reduction of high-water line.
0.3 mile	3.7 feet.
4.0 "	2.3 "
8.0 "	2.1 "
13.5 "	1.7 "
18.6 "	1.6 "
24.8 "	0.3 "

It may be mentioned here that the traffic on the Maas is inconsiderable above St. Andries, hence no injury in this respect is to be feared.

On the subject of outlets the testimony of the Dutch engineers was unanimous. The author gives such of their opinions as he made notes of:

"It is an axiom of river engineers that every river must carry its own water to the mouth. * * * * The Waal is injured by the overlaten from Heerewaarden to Loevestein. At high stages, as the river is loaded with silt, this latter is dropped by the sudden loss of velocity, so that recently considerable sums have been spent in restoring the depth by dredging. The outlet is also dangerous as regards ice gorges. Breaks in dikes have often the same consequences as overlaten—that is, a diminution of velocity below the crevasse, and hence ice gorges and new dangers.*

"The Dutch experience with outlets is all against them. They cause shallowing of the river, and hence (especially) ice gorges.†

"The overlaten were dangerous and detrimental on two grounds. First, they caused a slackening of the current, and, consequently, deposit and shallowing; and, second, by the same slackening the movement of ice was impeded and gorges formed. The principle is now utterly condemned.‡

"Formerly along all our large rivers we found such overlaten, which were made to allow the water to escape sideward, especially by an ice gorge. This system is generally out of practice at present, as it is stated to be no good at all. The river must be capable to carry off its own water. Therefore since 1861 we have been at work to normalize the rivers. * * * We may safely say that our wishes have been complied with in every respect, and the danger of ever having a flood again has vanished. The overlaten are filled up to the height of the dikes, and at present only two more exist in the southwest Maasdyk, namely, the Beersche Maas and the Bokhovensche Overlaat; but they will disappear as soon as the new mouth of the River Maas is ready."§

* Beekman, De Strijd om het Bestaan, pp. 49, 54.

† Notes of conversation with Messrs. Schnebbelie and Wisboom.

‡ Notes of conversation with Mr. Leemans.

§ MS. communication of Lieutenant Wenckebach, of the Dutch Engineers, 1889.

The work of building and repairing dikes or waterways, and, in fact, public work of any kind, seems to be done almost exclusively by contract. The work is carefully measured and staked out beforehand, cross-sectioned, and an accurate estimate of it made, such as we make for a final estimate. Persons intending to bid may employ their own engineers and remeasure the work if they please, for their own guidance. They then bid, not so much per cubic yard, but a gross sum for the whole. The specifications are of two kinds, general and special. For work under the civil department, or Waterstaat, the general specifications are those to which allusion has already often been made (the Algemeene Voorschriften). This is a volume of 248 pages, and contains standing regulations for the execution of all kinds of work—earth and dredging work, the construction of straw mats and of brushwork, of stonework, of pilework and timber-work, of work in metals, in masonry, calking, glazing, stucco, paper-hanging, road making, etc.; the requirements for materials, the duties and rights of the contracting parties, the responsibilities of bondsmen, etc.; a table of weights and measures, the lawful hours of work, and a quantity of miscellaneous instruction. This volume is for sale for one florin (say, forty cents), and is made a part of every contract, except so far as it may be superseded by special provisions in each instrument, in which case the modifications are particularly noted. The general specifications for work under the military engineers are contained in another volume entitled "Algemeene Voorwaarden," which is altogether different in arrangement, but covers nearly the same ground. The particular specifications in each case describe first the nature of the work to be done, with the grades, slopes and measurements, the materials to be employed, and, in short, every detail which is required for a thorough understanding of the work. They are accompanied by accurate drawings. One feature of the Dutch specifications is a list of uniform prices, as it is called, which is to regulate any bills for extra work. A few of these prices may be interesting to American engineers:

For digging, carting or loading 1 M^3 of ground.....	4	cents.
" carrying with wheelbarrow 40 M. level or 25 M. not steeper than 10 to 1........................	5.6	"
" carrying the same distance further.............	3.2	"
" carrying with cart over 100 M further..........	6	"
" " " " each 100 M.................	3.2	"
" 1 M^3 coarse screened gravel, rolled............	80	"

For one ship's ton ballast stone, delivered and placed in position	92	cents.
" 100 pieces perkoenpalen, oak, 1.60 M. long	$5.40	
" one stone setter, krammer or brush worker, per day of 10 hours	60	"
" one earthworker, or common laborer	50	"
" one cart with horse and driver	2.00	
" carriage and team per day	2.80	

The laborers are all natives, and form a peculiar class, called familiarly "polder-Jans," or, as a Mississippian might say, swamp-Jacks.*

Steam power is used a great deal on large works.

The construction of new dikes is generally or always undertaken by the Waterstaat of the kingdom, at least on the mainland. In Zeeland, which maintains an isolated existence, the several polders bear all their own expenses in this way if they are able; if not, they seek assistance from the state, and are then called *calamiteuse* polders. After the dikes are once built, however, their maintenance and enlargement are committed to the local authorities. The organization of the Waterstaat is said to be somewhat complicated, and effort was made to ascertain only its prominent features. The head of the department is the Minister of the Waterstaat, Commerce and Industry. He has an advisory staff, consisting of an inspector-general (Mr. Caland) and two inspectors (Mr. Conrad and Mr. ——). These are chosen from the chief engineers, not by seniority at all, but by selection. There is a chief engineer in charge of the great rivers—Mr. Leemans—and one each for very great works, as for the new Maas Mouth (Mr. Schnebbelie) and for the Merwede Canal (Mr. Wellan). Besides these there is a chief engineer for each province, and these have subordinates, one for each arrondissement, or more or less, according to necessity. The chiefs report directly to the minister, the inspectors being the latter's professional advisers. The chiefs themselves are not necessarily chosen from seniority, though this consideration has a great deal of weight. The inspector-general has his own particular sphere of action in the assignment to duty of subordinates, etc. The department of river gauges, etc., is his peculiar province. The two inspectors divide the kingdom between them territo-

* Jan is a common term in Holland for any waiter, driver, or other person in a low or menial station. It is usual to summon a waiter by calling him Jan.

rially, one having the northern and the other the southern department.* By the Constitution of 1848, the Crown has the supervision of everything that concerns the Waterstaat, including roads and bridges, whether the costs be paid by the general government or otherwise. The provincial estates have control, within their provinces, of all waters, bridges, etc., and are authorized, with the approval of the Crown, to make changes in the regulations appertaining thereto. The administrations of the waterschappen may propose such changes. The Estates have authority over all stripping of turf, in dikings, droogmakeryen, mines, etc., reserving the right of the Crown to delegate the immediate supervision of the same to agents appointed by it.

Local organization is somewhat irregular. In some provinces the polders are independent, and each has its own administration, with a presiding officer under one name or another. More commonly several or many polders, having the same interests, have united themselves into a *waterschap*, and maintain an active and powerful organization, with authority to impose taxes, etc. These bodies attend to the matters of general importance to the district, such as the drainage of the bosoms, defense against the outer water, etc. All the mainland of South Holland, all North Holland south of the Y and a part of Utrecht are divided into such great waterschappen, which also are found in other parts of the kingdom. They bear all sorts of names, *hoogheemraadschappen*, *polder-districten*, etc., mostly derived from the middle ages. The powers and duties of these bodies are very varied, some having control of all matters relating to the common interest, the draining and letting in of water, the maintenance of the river and sea dikes, the levying of taxes for these purposes, etc. Sometimes the tie is much looser, and the polders retain these affairs within their own jurisdiction, only sending representatives to annual meetings of the waterschap administration for the discussion of some specially important subject. The individual polders, of course, have their own management, which attends to their local interests and economy, under general regulations prescribed by the Provincial Estates.

There is another kind of body charged exclusively with the supervision of the dikes, and called accordingly *dijksbesturen*. The jurisdiction of these corporations is very different in different places. One part of them which exists in neaily all the provinces is called the "Daily Boards," generally appointed by the Crown for a term of years. With

* Notes of conversation with Mr. Leemans.

these are other members, either elected by the freeholders or appointed, by virtue of ancient rights, by corporations or even by individuals. Freeholders generally have votes in proportion to their possessions. The administrative board of a polder usually consists of a president or secretary, called bailiff, burgomaster or what not, and several members who go by the names of poldermasters, dike reeves, or the like.

The expenses of management, maintenance, repairs, etc., are usually borne by the landed proprietors in proportion to their property. In addition to the general charges of the waterschappen, the polders also have their separate budgets, which are sometimes considerable. As an example of these taxes, it may be mentioned that the acreage tax of the Rhineland waterschap from 1844 to 1867 averaged 1.40 florins per hectare, or say twenty-two cents an acre. The polder taxes were very irregular. In the grazing lands (the so-called cow polders), which lie comparatively high and have not expensive drainage, they amounted to from thirty-two to eighty cents per acre. In the deep droogmakeryen they sometimes went as high as $4 per acre. In the Haarlem Lake polder they were $1 per acre. The whole budget of the Rhineland district ranged from $100 000 to $120 000. That of the polders collectively was $160 000. For the whole province of South Holland, including the islands, the yearly contribution, in 1884, was about $1 300 000.* According to Baedeker, the annual expenditure of the whole kingdom for dikes is about $2 400 000.

A word should be said about the remarkable system of military inundations, by which it is proposed to lay certain portions of the country under water, in case of necessity, to obstruct the progress of an enemy. To give any intelligent exposition of this plan would require much more careful study than the author has given it, and much more information than he possesses. Suffice it to say that it is not designed, as might be supposed, to drown the enemy, but merely to make the roads impassable and the country untenable, and that it is necessarily applicable only to the low lying polder land, that is, North and South Holland and Utrecht. The inundations are to be produced by sluices specially contrived for the purpose, either so-called fan sluices † or sluices closed by stop plank, or

* Beekman, "Nederland als Polderland," pp. 125-132. Id. De Strijd om het Bestaan, 249.

† Waaijersluizen, an ingenious contrivance, with a gate composed of two leaves, each of which itself consists of two gates, at something less than a right angle to one another, and joined firmly together at the quoinpost. The second gate works closely in a sector-shaped recess in the wall of the head-bay. It is evident that the head against the one gate will neutralize that against the other.

simply by cutting away certain overlaten. These works are placed under the guns of powerful forts. Of course, the inundations are to be accompanied by vigorous military and naval operations.

The sea-coast of Holland is said to be about 1 500 miles in extent. Probably about 800 of it is protected by dikes. The author has seen somewhere an estimate of the length of the river dikes, placing it at more than 800 kilometers, or say 500 miles. The dikes are only a part of what Holland has found it necessary to do, to build up a country. Of enterprises recently completed or still in progress, the North Sea Canal, which gives Amsterdam its access to the ocean, cost $14 000 000; the New Waterway from Rotterdam to the sea, through the Hoek van Holland, cost $13 000 000; the Merwede Canal, from Amsterdam to the Waal, will cost $10 000 000; the new Maas Mouth will cost $6 000 000. The State which has accomplished all this has a superficies of 12 738 square miles and a population of about 4 600 000. It is impossible to visit Holland without an increasing admiration of the plucky, free, intelligent people who, by sheer force of industry and genius, have created for themselves a country almost against the will of nature. Surely the Dutch indulge in no empty boast when they say: "God made the sea and man made the land."

DISCUSSION.

A. F. Sears, M. Am. Soc. C. E.—I think Mr. Starling is entitled to our most cordial recognition of his energy and ability in the preparation of this paper, as well as for the industry and earnestness displayed in learning a foreign tongue that he might possess himself of all the necessary data. The paper is the more interesting to me, as I am about to proceed to the construction of important works of a similar nature to these dikes, of which it treats. I hope I shall not be considered hypercritical if I venture on one or two suggestions on behalf of myself and older members of the Society as well as for the benefit of younger members who look to our published *Transactions* as textbooks of both example and authority.

First, no document presented here can be made too clear. There should be no opening left for any misunderstanding. I think it a mistake not to have translated all the Dutch words that he has given us. All through the paper words are encountered which are, indeed, eventually explained, and of which the meaning is secured. But it would have

been better if, throughout the text, the author had used the English equivalents and exhibited the Dutch in brackets.

We have Hoofden, Zinkstukken, Droogmakeryen, belonging to no tongue that is classic to the American engineer; enclosed in brackets they might be interesting; the word "Perkoenpalen," we are told, is untranslatable, the reason being that even the Dutch engineers, themselves, are ignorant of its derivation. Now, the truth is, whatever we may say of the word, the American engineer has made use of the article ever since our profession has had a name in America. He has used it to anchor rafts in shallow water; to secure entanglements, whether of wire or brush, on the glacis or elsewhere in front of works; and to fasten sods on the face of dry sandy slopes; in short, for a hundred purposes, and as yet I have not heard that he ever encountered difficulty in securing them, if he called for anchor-stakes, or, more briefly, anchors.

Few engineers are permitted time to study rigid literary accuracy, but we may always keep in mind a remark of our own Hawthorne, "There is no word nor thought in any language that cannot be fully and accurately translated into the language of the American"—a thought of value to the engineer.

I beg your indulgence in making another criticism; I refer to the conglomerate statement of measures, the mixture of the American system of feet and inches with the metrical system of the European continent. If we wish to make our papers of the greatest use to our profession, we should, when using the foreign system, accompany it with the equivalent American value in brackets.

There is a doctrine of construction suggested in this paper that, I confess, surprises me. If it were simply an historical statement, I should have nothing to say about it. But, by the manner in which the statement is made, the author has conveyed what seems to be an opinion of his own so completely at variance with all experience and written testimony, that I think it extremely dangerous to leave it uncorrected. It is stated on page 577 as follows: "The material of the dike should, if possible, be clay, and should be taken from the outside. If clay cannot be had in that situation, then resort must be had to the inside. Sand has little cohesion and does not make a strong and water-tight dike." Farther on, the writer says: "There are examples of dikes that consist of very sandy material, with a dressing of only one meter of clay, and yet they turn water excellently. But it is easy to be seen that such a covering must be carefully treated and protected from injury, as, if the poor material be exposed, it cannot be trusted to exclude the water."

Now, as I have said, to an historical statement of the Dutch custom I have no objection; but I think Mr. Starling has misinterpreted the fact of the outside dressing of clay, in supposing it is put there for the purpose of making a water-tight bank. There can, I think, be no doubt

that it is there for a very different purpose. It is there because, by reason of its unctuous nature, it presents a lubricated surface, when wetted, to the action of the current, and thus impedes the bank's erosion more effectually than a mixture of sand and clay. But beyond all doubt for purposes of a water-tight work, there must be with clay a mixture of sand or gravel, or, what is better still, of both.

I have never yet seen a satisfactory analytical statement, accounting for the fact that clay is of use in a puddle bank, though I know it is almost universally so employed. Is clay used to fill the voids of the grosser material, or are the other materials used to fill the voids of clay? Both doctrines are taught with equal positiveness by the oracles. Every engineer's experience has taught him this interesting fact, that a bank of hard pan, which is largely sand and gravel cemented with clay, is vastly harder to excavate than a bank of pure clay can ever become.

My own experience in very early life furnished me a useful lesson in this direction. It was the custom, forty years ago, to leave all the details of coffer-dams to the contractor, on whom rested the responsibility of raising the work. The contractor in the case to which I refer was the late John Duff, who afterward became the Vice-President of the Union Pacific Railroad, and died a millionaire. Mr. Duff took charge of all the details, and gave his personal attention to the construction of a coffer-dam which it became necessary to build in Codorus Creek, on the line of the York and Harrisburg Railroad, in Pennsylvania. The structure consisted of sheet-piling enclosed in the customary yoke timbers, and forming a chamber 6 feet wide in water at that season about 12 feet deep. The bottom of the creek was a thin layer of silt overlying solid rock. The chamber of the coffer-dam was filled with pure clay from the banks of the creek, and the pumping began. It was soon discovered that a useless and expensive structure had been erected.

About this time the waves of revolution had stranded upon these shores an accomplished engineer who, under the patronage of the Appletons, undertook the publication of a book that should be authority on the subject of bridges. I had become a subscriber to this work of George Duggan, and received the number containing the chapter on coffer-dams while Duff and the rest of us were scratching our noddles over the puzzling problem. And here it is proper to remind you that in 1850 there was very little engineering literature in these States. I think the *Engineer and Architect's Journal* of London and the *American Railroad Journal* of this city were the only papers that professed any interest in our work. Later came the Appletons', edited by Julius W. Adams, Past President Am. Soc. C. E. But the work of Duggan solved the difficulty for us. We read: "However general may be the opinion, it is certain that one more erroneous was never entertained than that clay alone is a proper material to make a good coffer-dam." "All clays, when used in a coffer-dam, require a mixture of sand and gravel." These statements

are a summary of the entire treatise, which is carefully elaborated. It also mentions the fact that "in specifications for these works the usual expression is that a good retentive clay must be used."

I suppose that in very shoal water and in positions like those of the Dutch dikes, where the duration of exposure is not continued very long at any one time, it may be safe to use pure clay as a water-tight material; but certainly not in any considerable depth of water. To members who are interested in this subject I recommend this chapter from Duggan, the book having been presented to the Society by the late Mr. Trautwine. Many writers on this subject have given us the result of their experience since the time of Duggan, and none with more decided tone than the late William J. McAlpine, Past President Am. Soc. C. E., whose operations in sub-aqueous works we are all familiar with. Very lately—in November, 1890, and in August, 1891—Herbert M. Wilson, M. Am. Soc. C. E., presented papers to this Society on the Indian and American irrigation systems. Interesting and valuable statements on the subject under discussion may be found at pages 251-2 in the Indian paper, and pages 206 and 220 of the other, and doubtless also in other parts of the documents, though I do not happen to recall them at this moment.

Now, it would seem that in this day experienced professional men should not be found who can make the mistake of requiring the construction of a water-proof bank with pure clay. Not more than two years ago, however, I went to South America with an English engineer, a member of the Institution of Civil Engineers, who recommended a dam of masonry because there was not a mass of pure clay in the vicinity, the trouble being that all the clay he could discover was unfortunately mixed with sand and gravel. Important and disastrous facts like this must be my excuse for inflicting on you so considerable a discussion of what ought to have passed beyond discussion.

I observe a disposition to throw large cobble stones out of banks intended to be water tight. If the work is intended to carry a water conduit, and therefore subject to leakage, there may be reason in the precaution, though I very much doubt it; but an earth dam, which has been properly designed, will be improved by leaving the heavier material in the heart of the work, provided a suitable amount of good water-proof front has been left on the water face.

I observe with interest a statement on the 589th page of Mr. Starling's paper that may be adopted as an argument in favor of dams built of clear sand, notwithstanding the previous condemnation that material has received. He says, "At Domberg the encroachments of the sea have been so extensive that they are about to build a dike there to back up the streak of dunes that has already become too thin for safety, while the further inroads of the waves are prevented by strong revetments and a formidable series of hoofden [spur dikes], extending, it was said, all the way to Westkapelle. The dunes are justly regarded as of such

value, that extraordinary pains are taken to preserve them. Where there is a high beach, extending as far as the flood line, this, of itself. will protect the sand hills from everything excepting very high tides, Where the beach is not sufficiently high, sometimes efforts are made to raise it artificially by means of brush or reed screens, which will collect the loose sand, as it is blown about by the winds, and cause it to lodge under their lee until the screens themselves are buried." Here, then, we have the sand dike, one of the most common contrivances of nature all over the earth, for protecting the interests of her other higher contrivance—man.

These sand dikes are more common on the Pacific slope of this continent than on the Atlantic. I have observed on the Atlantic coast of the United States that the dunes are universal, but not so the dikes, which seem to exist only on the steepest shores. The Pacific shores have a steeper declivity, and there we find the dikes in great perfection; but the dunes are farther inland, where they exist at all, and attain less height than on the Atlantic coast. A remarkable instance of such a dike extends along the beach north of the Columbia River, to Shoalwater Bay. The waves and heavy surf along that shore have pounded the sand into a most compact and water-tight mass, some 10 feet higher than the adjacent land on the inner side of the beach, and no water passes through this dike during the highest flood tides. I lived three years behind such a dike as this on Ferrol Bay of Peru, and had a remarkable opportunity to see its water-proof capacity; for a river, which should have flowed into the Bay of Samanco, having burst its banks, came down over the pampas of Chimbote, and was held in a great lake by this dike, and remained there until a channel was cut for its outlet.

I presume it is safe to say that every member of this Society, who has lived in the hemlock region of New York, can recall instances of the resort to sand for stopping leaks in dams, because the miller said that "sand would get there when nothing else would."

C. B. Comstock, M. Am. Soc. C. E.—Unfortunately for most of us, a book in Dutch is a closed book, so that a debt of gratitude is due to any one who will give, as Major Starling has done, the results of his studies and of his personal investigations on the ground, in reference to hydraulic works in the Netherlands. Italy and the Netherlands have been the pioneers in, and almost the inventors of, hydraulic processes, and despite the American tendency to think most highly of what we have ourselves done, no one is well equipped unless he also knows what others have accomplished.

In the levees on the Mississippi, a common type has been one with a crown 8 feet wide and with side slopes of 3 to 1, banquettes not being habitually used. In Europe, on the other hand, river levees usually have somewhat steeper slopes, and often have greater top widths and banquettes, whenever the levees are high. Thus on the Po below the

Ticino the normal width on top for levees close to the river bank, established by the Superior Council of Public Works, is from 8 to 9 meters, with an external or land side slope of 2 to 1, and an internal slope of 3 to 2, above ordinary water, and of 2 to 1 below that level. At a meter and a half below the top of the levee there is a banquette from 6 to 10 meters wide. If the levee is well back from the river, the top width is 5 meters above the Ticino and 7 meters below, while the banquette is 3 meters below the top of the levee, and 5 to 7 meters wide whenever the levee is 6 meters high. The aggregate length of levees on the Po is 822 kilometers.

What is really needed for levees, is that the surface of the ground water as one follows it from the river side of the levee, at the high-water level, through the levee and the subjacent ground, to the ground water surface at some distance from the levee on the land side, shall everywhere be below the surface of the levee and of the adjacent ground. Now, where the levee is of good material, and below its foundation there is very sandy material, the above condition can be more cheaply fulfilled by a wide banquette on the land side than by a heavy levee without a banquette.

In this connection, the following notes as to German levees and levees on the Theiss, may be of interest.

Levees on the Rhine, in Germany.—The principal continuous levees begin at Cologne on the left bank and on the right bank below Cologne, at the boundary of the District of Düsseldorf. From this boundary the river valley increases from 1 to 10 kilometers in width, and near the Netherlands frontier is 25 kilometers wide. In this area are many portions of the old Rhine bed. These deserted portions in the course of centuries have been leveed, either against all floods or against summer floods, thus forming polders whose aggregate area is about 1 100 square kilometers. The levees are of three classes:

First.—Summer levees, which protect only against summer and not against winter floods.

Second.—Winter levees, which protect only against ordinary winter floods.

Third.—Bann levees, which protect against floods of all heights, save those produced by ice gorges.

The aggregate length of bann and winter levees is about 520 kilometers, or four times the length of this part of the river, and of summer levees is about 260 kilometers.

Almost everywhere the summer levees have bann levees or winter levees behind them.

The highest water at Cologne since 1816 was	9.52	meters, in Dec., 1882.	
" " " Düsseldorf " "	8.93	"	
Summer levees are raised to...............	5.90	"	on Düsseldorf gauge.
Winter " "	7.90	"	
Bann " "	9.50	"	

The flood discharge of the Rhine is 315 000 cubic feet per second at the Holland frontier.

The levees are 2 meters wide on top as a rule, this being increased to 3.5 or 4 meters when used as a road. River slopes are one-third and land slopes the same where not exposed to water. Where they are arranged for overfalls the slopes are from one-sixth to one-tenth.

Elbe Levees in Prussia.—The aggregate lengths of the Elbe levees in Prussia, from the Saxon frontier to the mouth of the Seeve, just above Hamburg, is 445 kilometers. They rise to from 0.6 to 1.0 meter above the highest floods. In the upper districts they have usually top widths of about 2 meters, with slopes of 3 to 1 on the river side and 2 to 1 on the land side.

Where the levees are 2.5 meters or more high, a banquette from 3 to 5 meters wide is placed on the land side at 2 meters below the crown. In the lower districts the top width is at least 2.9 meters, or 4.7 meters if used as a road; the river slopes are from 2 to 1 to 5 to 1, according to the material, and the land slopes from 3 to 2 to 2 to 1. Where it has not already been built, a banquette both outside and inside, 5.9 meters wide, is aimed at.

Vistula Levees in Prussia.—On the Vistula in Prussia, the aggregate length of winter levees is 366 kilometers, and of summer levees 30 kilometers. The levees have a top width of from 3.8 to 5 meters, and in the upper district usually a river slope of 3 to 1 and a land slope of 2 to 1 or 3 to 2. The strongest levees are below the forking of the Nogat. The normal profile for these levees has a top width of 5 meters, the slopes being those named above; 3 meters below the crown there is a banquette of 5 meters width. These full dimensions as respects slopes and banquette have been rarely reached. It will be seen that banquettes and steeper slopes than 3 to 1 on the land side, are used on the Elbe and the Vistula.

The Theiss is 1 025 kilometers long from the point where it enters the Hungarian plains to its mouth in the Danube. On it a large number of cut-offs have been made shortening the river by 478 kilometers. The plain of Hungary subject to inundation is about 600 kilometers long. In 1879, in consequence of breaks in the levee above Szegedin, that city of 70,000 inhabitants was nearly destroyed. The flood was 9.60 meters above lowest water. Szegedin was from 2 to 4 meters below the flood level. In 1872 there had already been built 1 200 kilometers of levees, and since the destruction of Szegedin in 1879 the levees have been greatly strengthened and improved.

Between the Körös and the Danube, the following is the general type of levee adopted:

Height, 1.50 meters above high water.

Top width, 6.0 meters.

River slope, 4 to 1 below high water and 2 to 1 above.

Land slope, 2 to 1.

Banquette on land side, 4 meters wide, and 1.0 meter below high water. Here, as on the Po, much greater top widths are given to levees than is usual on the Mississippi.

Desmond FitzGerald, M. Am. Soc. C. E.—The writer of this paper is entitled to great credit for the care and labor expended in presenting to the Society the results of his researches into the details of dike building in Holland. It enforces the magnitude and variety of the engineer's work, and the widely different conditions under which it is carried on in different portions of the globe. The principles, however, which underlie all public work are the same the world over, and must be met in one way or another, or failure will ensue.

I notice in the first place that Mr. Starling has called attention to the fact that slopes of less than 2 to 1 are considered unfavorable for the growth of grass in the Netherlands, and that therefore this rate is prescribed. This accords closely with my own experience in the case of the slopes of the embankments on the Sudbury and Cochituate Aqueducts of the Boston Water Works. I have found it extremely difficult to maintain grass slopes on inclinations of 1½ to 1. It is a constant fight with the elements, no matter what care is used. On northerly exposures the troubles are of one class, and on southerly slopes of another, but the final result is pretty much the same.

The Boston Water Works has been a fruitful source of experience in the line of earthen dam construction and of high embankments for the support of masonry structures. In regard to the latter, earth embankments have been carried to a height of nearly fifty feet by Mr. Davis and Mr. Fteley, with a settlement of less than 1 inch, but it is needless to say that they have been built with great care, of excellent gravel, rolled in thin layers. The dams have generally masonry cores, carried down to the rock, or to fine sand or other good bottom, at a considerable depth. In a dam now building we have carried the concrete wall down to rock, at a depth of 40 feet in one place below the surface. For permanent work, whenever the damages from failure are likely to be great, or loss of life comes into question, it does not pay to take any risks.

For one, I particularly appreciate the reference to the practice of the Dutch engineers in allowing plenty of margin against the upward pressure of water. I have seen works designed with an utter disregard to this law. It is no uncommon thing to see gate-houses, for instance, built with massive side walls but with hardly any protection against the blowing up of the floors, and, perhaps, it may not be out of place to emphasize what Mr. Starling has so well said on this point.

In sinking core walls or puddle trenches to considerable depth, great care should be exercised not to disturb the fine material in the natural soil adjacent to the trenches; in other words, not to pump too much

muddy water; but how this is to be accomplished in many situations may well bother the engineer.

BOLTON W. DECOURCEY, M. Am. Soc. C. E.—Mr. Starling's "Notes on the Holland Dikes," is most interesting reading for members of the profession in the State of Washington.

The large area of the "tide lands and mud flats" belonging to the State and soon to be offered for sale, when properly reclaimed, will afford western Washington a large amount of level acreage of the richest alluvial soil for farming purposes, and will require a proper system of dikes, both maritime and fluvial, before it can be made properly available.

On page 580, where Mr. Starling speaks of tree protection, I would like to ask him if any use has been made of the matting tendency of the roots of the yellow or basket osier? I have seen them successfully used in cases of sliding banks, also as an excellent protection against the erosion by currents.

On page 582, regarding the ends of spurs, he says, "This is not according to our practice." I would ask what is the practice on the Mississippi and which does he consider the better? I would also ask if the problem to be worked out by the Mississippi civil engineers be not more difficult, preservation and improvement of the river navigation in that case entering largely into the question?

I was engaged on the Illinois Central Railroad, South, in 1882, and saw the floods in Mississippi and Kentucky, and also the high water of the following year, and remember the difficulties entailed by the tremendous force and the long duration of the flood.

The diking of the mud flats of the estuary of the Chehalis River will be probably entered upon in the near future. This is a large estuary with a total rainfall per annum of 5 798 707 200 000 cubic feet, completely protected from evaporation by the densest growth of timber and underbrush, and what may be called a supersoil of partly decayed vegetable matter as porous as a sponge, in which a person will sink from 18 to 24 inches as he walks. In making a reconaissance of seventeen days' duration in the autumn of 1889, through the Olympics, this so retarded progress that I found it impossible to do better than 5 miles per day.

The consequence is that freshets are not great, but the river carries silt all the year round, and what is called Grays Harbor, at the embouchure of the Chehalis, is a delta, the areas between the channels, which are perfectly defined at low water, being composed of this silt, there being only 2 to 3 feet of water over the greater portion at high water. There is a large acreage, which in the memory of parties living near was some years ago nothing but soft mud, acquiring its first coat of grass. The proper diking of these mud flats will concentrate the stream, and so improve the navigation. The system for providing the funds for this improvement and the personnel of the staff to be engaged in the superintendence of the reclamation, will have to be provided, and

it is to be hoped that the best talent and skill will be procured for the task.

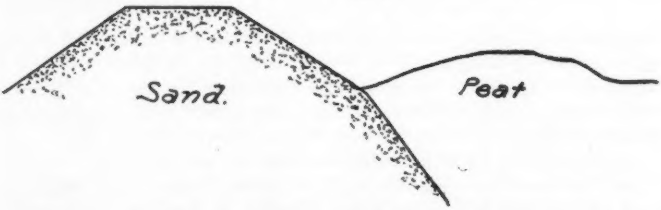
From the success secured in Florida by the use of bituminous rock in sea walls, it should be given a good test in maritime dikes and jetties.

W. HOWARD WHITE, M. Am. Soc. C. E.—Mr. Starling's interesting paper fills a considerable gap in the engineering literature of this country.

From his comment on the Dutch experience and maxims as to river overflows, I judge that he fully endorses the policy of confining the outflow of the Mississippi to a very limited number of mouths, and that he would certainly not advocate additional lateral outlets above or below New Orleans. His opinion on this point would be very interesting.

I note in the section Fig. 8, page 648, that the curving upwards of the sand under the peat seems to be an oversight. I take it that the section in such cases is rather as given below, the sand being prevented

FIG. 1.



by the lateral pressure from taking as great a slope as the natural one. The mud or peat being lighter, can flow or rise up, but the sand being the operating force, could never run out under the peat at a flatter slope than its natural one.

I take it that the use of banquettes for preventing the blowing up of the top stratum inside the dike must be limited to cases where the surface of the country inside the dike is generally (viz., except for short periods of time) above the water surface outside the dike.

Referring to Mr. Starling's Fig. 1, page 569, it seems evident that if the water surface were maintained, as shown, for a sufficiently long period, no banquette that could be built, either inside or out, would be of much utility, since the water pressure would gradually reach beyond the banquette, however wide, and blow up the soil at the first weak point found. If I am correct in this view, it would seem that the long periods of high water in the Mississippi must be unfavorable to protection by banquettes. It would appear in such cases that where the bottom muck is too deep to be cut down to impervious bottom by a puddle bank, the reliance must be on a secondary levee, such as Mr.

Starling describes on page 571, in which a body of water takes the place of the banquette. Presumably the "sand boils," Fig. 6, page 603, act as safety valves in such a case, relieving the subterranean pressure to such an extent as to prevent the blowing up of large areas.

An interesting question somewhat connected with the dike problem, though really on a different basis, is the utility of berms on dam slopes as shown by the full line, Fig. 2. The argument for these is that they tend to check slides. At least this is the only one I have heard. I argue

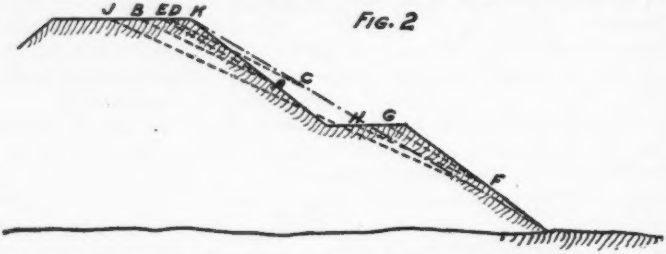


FIG. 2

that the same material put into the form shown by the broken and dotted line on the right-hand side of Fig. 2 would be less liable to slide and therefore less liable to cause damage than when the same material was formed into a berm, with steeper slopes above and below, largely on the principle that an ounce of prevention is worth a pound of cure.

A slide takes place ordinarily because the material becomes sufficiently saturated to make the angle of repose flatter than it originally was. Once started, it is extremely difficult to stop; first, because the sliding of the mass forms a more or less smooth surface for the highest material to slide down on; second, because the sliding rubs off more and more material; and third, because the removal of the material which has slid down tends to still further reduce the angle of repose by the very removal of the material on top of the sliding joint. We see the reverse of this process in the case of the pressure against a revetment wall, where the prism of pressure is only half as large as the mass above the angle of repose.

The possible slides in a dam with a berm divide themselves into four cases: 1st. When the sliding surface is steeper or parallel to the broken and dotted line and above the berm as shown by *AE*. It is obvious that in this case the amended profile is the best, since it would be unaffected, while with the berm profile a good deal of the crown would be lost, apart from the danger that overloading the berm would cause a slip below. 2d. When the sliding surface is flatter than the broken and dotted line and above the berm, as shown by *AB*. Here, the amended profile still has an advantage, since the part of the dam removed by the same angle of slope would be *CDK*, which is much less in amount. 3d.

When the sliding plane is steeper than, or parallel to, the amended slope, and below the berm, as shown by *FG*. Here, the amended profile still remains more advantageous, since no slide would take place. 4th. When the sliding is flatter than the amended slope and below the berm, as per *FH*. Here, for the first time, the berm profile has an advantage, since the sliding plane on the amended profile would come inside of *FH*, as shown by *IJ*.

An important factor, then, is in what position slides generally occur. Since the lowering of the water in the reservoir is the most frequent cause of such slides, it seems pretty certain that they are mostly to be expected in the upper portion of the dam, which is more frequently laid bare. It is this portion, too, which is most liable to the action of frost.

Hence, as I said above, I see no advantage for a reservoir dam in using berms on the slopes, in preference to putting the same amount of material into a dam.

J. T. Fanning, M. Am. Soc. C. E.—Mr. Starling says in opening his paper, that "the most remarkable sea-works which he visited filled him with admiration, but also with despair, as there seemed hardly a possibility of ever being able to imitate them." The alluvial districts of Holland until within a few centuries represented the resultant of a long continued struggle between the rivers Rhine and Meuse and the North Sea. The power of the rivers was steadily and persistently transferring the foot-hills of the Alps into the bed of the sea and advancing the shore. The sea as persistently dashed back the deposits or spread them aside.

Then came man to possess and use the delta lands thus formed, and then began his efforts to wall out the sea and to confine the rivers in their many channels. First came the Batavians, then the Danes, the Normans, and then the Saxons.

After a moderate success in diking portions of the delta, there came a great storm, destroying dikes and giving victory to the waters, most disastrous to humanity. This victory was not final, however, for then the engineer, as a skilled designer and director, was called to be a leader in the contest. The works of the engineer in the Netherlands may well fill a student of them with admiration. He may be conscious of the improbability of ever being able to "imitate the most admirable of these works," but if he appreciates their true significance and receives their broad teachings, they will be an inspiration when some duty, that is great to him, comes in his way.

Venice is a city of canals, with the sea flowing and ebbing through at will. Amsterdam, on the other hand, is a city of canals with the sea shut out, or flowing and ebbing only at the pleasure of the engineer. Amsterdam was at first diked off from an arm of the sea, and then it was made a crescent city, with concentric canals that admitted maritime commerce to its heart, or permitted distribution of commerce near its circumference.

The harbor of Amsterdam was, later, shut off from the Zuider Zee by a greater and more admirable dike, exposed to a long reach and powerful effect of storm waves. This great Schellingwoude dike is an illustration of many of the principles adapted to sea-works which Mr. Starling has industriously compiled and presented in his paper. It has five locks, the largest of which are adapted to sea-going vessels of heavy burden; it has inflow and outflow sluices in admirable masonries, and steam pumps of modern design. This great dike shuts out the eastern waters of the sea and creates a harbor protected from the waves, where a multitude of ships and steamers lie at anchor, moor at wharves, or enter the network of city canals in safety. It is also the eastern outwork of the modern North Sea Canal which gives Amsterdam commercial prominence among Dutch cities.

Here, again, in and near the canal and its Ijmuiden Haven, many principles which the author has stated are amply illustrated. This canal, 15 miles in length, extends westerly from Amsterdam to the North Sea. On either side of the channel may be seen canal embankments; polder levees; railway and highway embankments; canals for internal commerce and travel and for drainage; locks for the entrance and exit of craft; sluices for drainage and irrigation; steam and windmill pumps; meers lying lower than the ocean; dunes of sand deposited by the winds near the sea shore, and along the shore a great dike of sand thrown up by the sea. At Ijmuiden are locks, the greatest seventy-two feet in width, that pass ocean steamers as well as coasting packets and the fleet of fishing smacks that have quickly made Ijmuiden a fish mart. These locks represent, in foundations, masonries and gates, the condensed hydraulic experiences and skill of centuries in the Netherlands. The locks are founded in a broad and high ridge of sea-thrown sand. At Ijmuiden is also an artificial haven made by projecting two remarkable breakwaters, each three-quarters of a mile long, from the sand hill into the open sea.

This is all a field full of varied and interesting examples of hydraulic constructions, and the influence of its teachings now shows in several directions; for instance, in larger locks between Manchester and the Mersey Inlet, and at our own Sault Ste. Marie between the lakes.

The Haarlem-mer Meer Polder extends nearly to the North Sea Canal, and is seen on the left of the railway from Amsterdam to Haarlem. This polder has, perhaps, a larger place in the imagination of the American schoolboy than any other of the wonders of the Netherlands. He has read of the great lake of 70 square miles area that was surrounded with dike and canal and drained by three enormous pumps working nearly three years continuously, a half century ago, and of farms and homes thus made for ten thousand people.

The description of the first of these great steam pumping engines, with its largest steam cylinder 12 feet in diameter and smaller steam

cylinder 7 feet in diameter, with 10-foot stroke, and the eleven great pumps arranged in a circle around, and all worked by this one engine, has often excited the interest of young mechanicians, as they have read that these pumps could lift 63 tons or nearly 17 000 gallons of water per stroke out of the polder drain. The writer, when in Holland, remembered that when the sea broke into the lands now forming this polder, it washed as far as the rear sluices of Amsterdam on one hand and Haarlem on the other, and endangered those cities. Naturally, he inferred that the famous "Leeghwater" pump must still be an object of interest among the generation it had protected. Alas! on diligent inquiry in a leading hotel in Amsterdam for directions to reach the "Leeghwater," no one connected with the hostelry had seen it or could tell where it was located. Soon after, in the City of Haarlem, inquiry was again made for the Leeghwater machine, first of several merchants near the railway station and then at the hotel, with fruitless results for a time; but at last, a guide was found who had once taken a party to a great steam pump some miles distant in the meer. This machine proved to be one of the two mates of the Leeghwater, the "Cruquis." These three ponderous pumping machines are at separated points in the circumference of the meer, the Leeghwater being in the south, the Cruquis on the west, near Haarlem, and the "Van Lynden" on the east.

Had Mr. Starling referred the "despair," mentioned in the opening of this paper, to his hopes of gathering in a foreign land so much valuable technical information as he has presented to us, he would have touched many a sympathetic chord among those who have tried with less success. Undoubtedly he could often give to those of whom he inquired more of the history of the specialties he went to study than they could give to him. This monograph will, next to the personal inspection and study of the interesting hydraulic works of the Netherlands, be rich in instruction, suggestion and inspiration to the engineers who have to direct works of importance such as are now frequently projected in America.

We still have opportunities for the best efforts in confining the Mississippi River floods and adapting the river channels to commercial needs; checking the meanderings of the Missouri River back and forth across its broad valleys; deepening the channels and constructing locks between our great lakes, and between the lakes and the ocean; transporting commerce between our Gulf and the Pacific, the Bay of Fundy and the St. Lawrence, and other equally grand works, for which this monograph offers suggestions in preliminary studies.

The surprising extent and success of the difficult hydraulic works accomplished in Holland may give us courage in projecting, and our capital confidence in aiding, great works that will be of much benefit, as it is now giving Dutch engineers and capital, courage to project the reclamation of 700 square miles additional of the shallow Zuider Zee. The les-

son for us in this monograph is not only how dikes and sluices are made in Holland, but that these dikes and sluices, in their best forms, are the summations of thoughtful, earnest experience of several centuries in works whose failures, if they fail, lead to dire disasters. The monograph teaches also that the rolls of the storm wave and the floods of the river may be stayed and guided by "mud" if the mud be "mixed with brains."

Mr. Starling closes with the Dutch saying: "God made the sea and man made the land." The impression comes to a studious examiner of these lowland hydraulics, that God has there permitted the powers of the river and of the sea to long struggle together, and then has permitted the learned skill of the engineer to overcome them both and take the spoils, which are the Netherlands.

HENRY B. RICHARDSON, M. Am. Soc. C. E.—Mr. Starling, in this paper, has given the Society a condensed body of information relative to the dikes of Holland, checked by personal observation, which cannot fail to interest the profession, and to be of special service to those of us who are occupied with similar constructions.

The Dutch earthworks, designed for protection against inundation by river floods, appear to closely resemble in all material features the levees of this country on the lower Mississippi and its tributary and effluent streams. The form and proportions of the sections used under like conditions, the character of the material entering into their structure, and the dangers and defects that threaten their integrity, seem to differ less than the climates and customs of the countries they serve to defend. In both countries the systems of dikes and levees are plainly evolutions from small beginnings—probably as yet not fully developed in either.

Some of the most obvious points of difference seem to be the following: (1) In form of section and proportions, the Dutch works have generally wider crowns than ours—presumably due to the longer time during which additions to their width, or general enlargements of section, have been carried on. A large and increasing proportion of the levee work on the Mississippi River for the past six or eight years has been the enlargement of cross section, involving width of crown as well as other dimensions, so that in course of time it is probable that the width of the Mississippi levees may become as great as those of the Dutch levees.

The digging of "muck ditches" of some sort, as Mr. Starling notes—though not greatly favored by the Dutch engineers—is an almost invariable practice in the construction of levees on the Mississippi.

They are of undoubted service in cutting off roots and minor subsurface cavities caused by decayed roots or by burrowing animals, and their omission under any levee would be regarded with astonishment and alarm by most of the "oldest inhabitants" of the Mississippi Valley—

who, by the way, are mostly hydraulic engineers of the practical school, with whom the "muck ditch" is a cherished institution—"tongueing and grooving," as it were, the levee to the solid earth, and among whom there is a prevalent belief that in Holland they cut their "muck ditches" at least as deep as the levee is high.

But it is not always apparent that such ditches as are usual—say, 3 feet deep—have any appreciable effect in cutting off "sipe-water," which always, to a greater or less extent, filters through the natural pores of the soil – and it has not been observed, in Louisiana at least, that in the few cases where much deeper ditches—say 10 feet and over—have been cut and carefully filled with fairly good puddling earth, that the total "sipe-water" was materially reduced, though it might show itself somewhat further away from the levee. But in numerous cases where old levees, dangerously leaky from perforations of burrowing animals, have had a muck ditch of ordinary dimensions cut along the foot of their front slopes, and have then been enlarged on that side so as to cover the ditch with the earth of the new section, the trouble has generally been reduced to insignificance, if not completely cured.

(2) In the character of the material of which dikes and levees are constructed, it would appear that little difference exists in the earth near at hand, of which they must be mostly formed, except that true clay is perhaps of more frequent occurrence in Holland than here, and that the Dutch have peat bogs to contend with, which are not to be found in the valley of the lower Mississippi. Those parts of the structure that consist of a protective covering of the earthen embankment, are naturally more elaborate in Holland than in this country, where the use of stone and brick for revetment has never been attempted—presumably on account of their larger first cost, and of the fact that few levees here are yet considered in such a state of completion that it is not expected they will at some time be further enlarged and improved. To undertake in this country, and upon levees which, within a few years, it is expected to enlarge and regrade, such careful and costly work in straw, brick and stone, as is applied by the Dutch to many of their embankments, would plainly be uneconomical, and the less expensive—if also less durable—wooden revetments in use here, are, perhaps, under the circumstances, better adaptations of means to ends than could be effected with less perishable materials.

(3) There seems to be a greater difference between the kinds of danger—if not in their degree—to which the river dikes of Holland on the one hand, and the levees of the lower Mississippi Valley on the other, are subjected, than in almost any other aspect in which they can be compared or contrasted; in fact, so great a difference in one particular—at least so far as stated in this paper—that it is to be wondered at that the author has failed to give it special notice.

Of the many dangers that menace the integrity and efficiency of levees

in the lower Mississippi Valley, no one will deny that the tunneling operations of the various burrowing animals whose habitat is there, are among the most persistent and difficult to deal with. The cray-fish, the fiddler-crab, the musk-rat, and sometimes the beaver and two or three other rarer burrowers, are certainly to be held responsible for great numbers of leaky places in and under the levees of the lower Mississippi, and several disastrous crevasses have been caused by their mining work. No doubt they have been charged at times with evil acts of which they may be innocent; but there are evidences enough that they should be classed among the dangerous and suspicious classes. If such pests are not to be found infesting the Dutch embankments, these are surely exempt from one of the perils which constantly threaten some of the dikes of this country.

In another respect the Dutch seem to be fortunate. The rivers of the Netherlands evidently do not eat away their banks in such an enormous and insatiable way as does the Mississippi, and their appetites in that direction are more easily restrained than that of the Father of Waters. Hence, with them, the necessity of falling back to new locations with the lines of levees is less frequent and less in amount than in this country. A few years ago official records showed that three-fourths of the levee work done in Louisiana, within the previous seven years, had become necessary on account of caving river banks, which required levee lines to be moved to new locations. The necessity for such extensive changes of location from this cause is undoubtedly rare in Holland, and it should be added, is becoming less frequent on the Mississippi, though the causes that may require it are still active in most concave bends of the stream.

Mr. Starling has noted the great peril caused to the Dutch river dikes by ice and ice gorges, and the fact that danger from this cause is unknown in the lower Mississippi Valley.

As regards the dangers due to soft foundations, and loose and porous "underground," it would appear that on account of the numerous heavy dikes built across old channels in Holland, the Dutch have probably had more difficulties, from the sinking and displacement of foundations, to contend with than have been encountered in this country, and it is instructive and encouraging to find that the experience of their engineers has led to greater reliance in such cases upon earth and earth alone, which is in accordance with the general practice here, rather than upon grillages of fascine work or like devices.

A precaution that should tend to diminish or utilize even the displacement of soft material underlying the site of heavy embankments, that seems worth taking, though often neglected, to their cost, by contractors, is to begin the bank in two parallel and separate lines near the edges of the base as designed for the main embankment. By this means a part of the displacements set up in each direction from the two banks,

as begun, will meet in the middle of the main embankment, and, for the time at least, become either neutral, or only upward, in a useful direction.

The dangers resulting from pressure transmitted through loose and porous soils underlying tougher and less pervious strata, as illustrated by Fig. 1 of this paper, have not heretofore been generally considered by the levee builders in the Mississippi Valley of such a threatening and alarming character as it appears, from the extraordinary precautions taken against them by the Dutch, they are regarded in Holland. Were it not that the author states that five breaks, which took place in 1890 in one levee district of the State of Mississippi, are believed to have been due to this, it might, so far as previous recorded experience goes, be supposed a danger almost confined to the Netherlands.

It is true that opportunities for accurate determination of the immediate causes of crevasses are somewhat rare. Those breaks that occur unexpectedly in levees that have previously presented a safe and sound external appearance, are not often seen at the instant they break out, and usually they cannot run very long without so washing out the adjacent soil and flooding their entire surroundings, as to leave few visible indications of the causes producing them. It may, therefore, be possible that many breaks in levees have been due to this cause which have been attributed to other causes, or recorded as of unknown origin; but it may be stated that in the official records of the past quarter century relative to the hundreds of crevasses that have occurred in the levees of Louisiana, there is no mention or indication of the "blowing up" of a superficial layer of strong soil by pressure transmitted through or by an underlying weak soil. We may conceive an experimental illustration where an enclosed sand filter having its discharge orifice covered with a tough integument, is put under pressure till the tension on the covering membrane is sufficient to cause rupture. But in such an experiment we should hardly expect to see the sand blown out also, to any such extent as to produce a free flow of water; that is, to have the explosion of the membrane followed or accompanied by a crevasse in the sand behind it.

That such dangers as the author describes are possible must be admitted; but in the absence of direct proof that such "blow-ups" have occurred from pressure transmitted by semi-fluid soils, or by water pressure through the natural interstices of the soil, is it not a more reasonable hypothesis that in cases where such "blow-ups" have seemed to show themselves, the pressure that produced them has been transmitted directly through some vacancy or conduit of larger calibre than the pores, or natural voids, in any kind of earth?

However, if the danger exists, it should be guarded against; and the method employed in Holland of building inner berms or banquettes seems to afford at least a palliative remedy and is to be commended. In

Louisiana it has long been the practice to build such banquettes across all considerable slough bayous and other undrained depressions. They have perhaps "builded wiser than they knew"; but it is not supposed by anybody that these structures were intended by their designers to meet exactly the same dangers for which it seems they are used in Holland.

The Dutch have unquestionably greater difficulties to overcome in reclaiming their country from the sea and in its protection against river floods than will ever be encountered in the protection of the valley of the Mississippi from overflow, but the situation and the opportunities for reclamation of both are sufficiently similar to make the methods and experience of the older country most interesting and instructive to those engaged in like undertakings in the younger. Our thanks are due to Mr. Starling for the carefully selected practical details of the Dutch practice as presented in this paper.

Arthur Hider, M. Am. Soc. C. E.—The elaborate description of the dike work in Holland presented by Mr. Starling, is of great interest, especially to those engaged in levee construction along the Mississippi River, where the conditions are somewhat analogous. All the engineers engaged in this particular line of work are greatly indebted to him for his carefully prepared and complete description of these interesting works, the experience and methods in use there in many cases being very similar to our own.

In comparing the methods of the Dutch in dike work with the present practice of levee building on the Mississippi River, there seems to be a difference of opinion among the engineers in Holland, as well as those engaged in similar work on the Mississippi—this is the value and necessity of an interior core of earth or "muck ditch" below the natural surface of the ground under the base of the levee. The almost universal practice for years on the Mississippi has been the construction of these ditches in all new levees; they have been made of varying dimensions, from 3 feet on the bottom and 3 feet deep with side slopes 1 to 1, to the size stated in the original paper of 6 feet on the bottom, 6 feet deep and side slopes ½ to 1, and even larger.

Before discussing the merits of this ditch as an additional safeguard to the stability of the embankment itself, the nature and condition of the soil upon which the levee rests, as well as the method of its construction, should be understood. The soil is alluvial, and is composed of layers of sandy loam, sand, clay and silt of different degrees of tenacity and porosity; these layers vary in thickness from 2 to 25 feet or more, and occur in irregular order; at some points the top layer is sand, at others clay or silt, the relative position of the layers depending on locality. As a general thing, the lighter strata, sandy loam and sand, are found on the highest grounds, or "ridges," as they are termed, and the denser clay and silt in the swamps and low ground. As a matter of

economy, the ridges are generally selected as the locations for the levees wherever practicable, and the result is that the levee is frequently upon an underlying stratum of extreme porosity which is several feet in thickness.

The present method of levee construction usually followed is, briefly: first, to clear the base of all undergrowth and trees, grub out the stumps and roots, plow the base of the levee, dig the muck ditch, and refill it even with the surface of the ground with the best material at hand, preferably by the use of teams and scrapers, and then complete the embankment to grade either with wheelbarrows or scrapers; no particular care being taken to build it up in layers, or to compact it more than would occur by teams passing to and fro. The embankment is then sodded with tufts of Bermuda grass 2 feet apart. The section for levees of heights not exceeding 15 feet now generally adopted is 8 feet crown, side slopes 3 to 1. In the older levees no effort was made to grub out the stumps; they were cut off at a convenient height and left standing.

The utility and necessity of an interior core or "muck ditch," where the top stratum is of clay of any considerable thickness, is questionable; the fact that the stratum of clay itself is impervious to water and reaches far below the interior core, would seem to indicate that the digging of the ditch would be unnecessary. Again, where the top stratum is of sand, the building of a core 6 feet or less in depth of clay into a layer of sand which perhaps extends 20 feet or more below it, would have little effect in preventing leakage due to hydrostatic pressure. Instances are common where driven wells taking water 30 to 35 feet below the surface become flowing wells during high water. A levee line of 4 miles in length is now being repaired, built a few years ago with the usual muck ditch, the foundation of which is about 8 feet of loam and clay, below this a layer of about 3 feet of sand, then again a layer of clay. This levee was considered dangerous, as "sand boils," some of them of large dimensions, developed on the land side, being more frequently close to the base, and occasionally as far as 150 feet beyond. Innumerable other instances could be cited where the "muck ditch" failed to prevent leakage.

Another fact that renders the construction of these ditches expensive or inefficient in many locations, is the difficulty of getting proper material with which to fill them. On sandy locations there is frequently no suitable material to be obtained nearer than a mile or more and the result is that the best of the material close at hand is used, or that the expense of this particular part of the work is increased from 200 to 300 per cent. Usually, the best of the material close at hand is used, but this is often ill adapted to the purpose. It is admitted that where the ditch is properly constructed of good material and extends through porous ground into a thick stratum of clay, it is a desirable adjunct to the stability of the levee, as well as the most economical method of preventing leakage, but it is

believed the instances, taking the whole line of Mississippi levees, are few where these conditions exist.

The practice of adding banquettes to the Mississippi levees to give additional security on weak and bad foundations has not been nearly so generally followed here as in Holland, although within the past two or three years this method has come into more favor. From an observation of several years, it appears that the addition of a banquette 20 feet or more wide to the land side of all levees of over 6 feet in height, would afford greater security than the construction of the "muck ditch," which under the peculiar conditions of the soil is of doubtful utility for the purpose intended, the cost of the "muck ditch" as now constructed should be put into the banquette. In exceptional cases the "muck ditch" might be used to advantage. This would afford a larger section where most needed, preventing sipage and leakage near the base, and the danger of sloughing off of the back slope, which occurs often when the levees have become saturated after the water has stood against them for a long period. The additional earth would reduce the danger from percolation and sipage of water through the levee near the base, and the added weight of the banquette would overcome the tendency of the water to force its way up on the inside near the base, due to the head on the other side. The banquette would afford a roadway at all seasons of the year without injury to the main levee, an important consideration during high water, when the surface roads due to sipe water are practically impassable to vehicles.

The cost of adding a banquette 20 feet in width to the main levee with 8 feet crown, front slope 3 to 1, back slope 2 to 1—compared with one of standard section mentioned above—would be:

For an	8-foot levee	 85	per cent. of cost of standard section.
"	10 "	 94	" " " "
"	12 "	 99	" " " "
"	14 "	 101	" " " "
"	16 "	 102	" " " "
"	18 "	 102	" " " "
"	20 "	 102	" " " "

It will be seen that for levees up to 12 feet in height the cost would be somewhat less; between 12 and 20 feet in height, from 1 to 2 per cent. greater (putting the cost per cubic yards of the muck ditch the same as the embankment in the levee proper), but in practice the muck ditch is more expensive, so that really there would be no addition to the cost by the change.

It is believed that the modifications suggested would add to the stability of the levees and reduce the danger of crevasses. What the levees generally need is "more dirt."

J. Francis Le Baron, M. Am. Soc. C. E.—I have read with a great deal of pleasure the very full and interesting paper on the "Holland Dikes," by our esteemed member, Mr. Starling. This is a subject of much interest to engineers in many parts of this country, and especially in Florida and Georgia.

In those two States some beginnings have been made in reclaiming large tracts of swamp lands and many more projects are receiving attention. There are vast areas in both States which if properly drained and diked will be rendered the richest and most valuable lands now covered by water. I have lately been employed as consulting engineer, in preparing designs and formulating plans for the reclamation of the great Okefinokee Swamp, in Georgia, and also the Holpati Saw Grass, situated at the source of the St. John's River, in Florida.

Okefinokee Swamp comprises an area of 676.35 square miles, and the swamp and water shed together is 1 262 square miles. It is the source of the Suwanee and the St. Mary's rivers. The lowest part of the swamp is 107.5 feet, and on the northern and eastern edges it is 125 feet above the sea.

It is proposed to drain this swamp into the St. Mary's River, and the work is now in actual progress. The swamp being some 10 to 15 feet higher on the edges than in the center, it is possible to drain a large portion, about one-third of it, eastward into the St. Mary's River, without drawing off the water from the center, which can be drained into the Suwanee River, or later the whole swamp can be drained into the St. Mary's River by simply deepening the canal, provided the drainage of the first portion, which is now being done, proves a success, and the fertility of the soil sustains the expectations of the projectors.

This swamp contains a large amount of valuable cedar and cypress timber, and the projectors desired to so arrange the effluent canal that this timber could be floated out and return a profit, long before the land could be made available for cultivation.

The swamp is bounded on the eastern side or toward the St. Mary's River by a rim of sandy land, underlaid with clay at about 10 to 15 feet, and there are some half dozen small branches, tributary to the St. Mary's River, that take their rise in the eastern base of this enclosing rim or mound.

The St. Mary's and the Suwanee both issue from the southern edge of the swamp, and the first named swings round and runs almost due north for about 33 miles, nearly parallel to the eastern edge of the swamp, until about opposite its northern quarter, when it turns abruptly eastward and flows into Cumberland Sound. By cutting the canal through this surrounding rim, nearly east into the St. Mary's, the distance is found to be 6.98 miles. If the drainage of the swamp was the only object, the effluent canal would naturally be located through the narrowest part of the ridge into one of the several creeks before men-

tioned, which would carry the drainage into the St. Mary's; but as it is desired to float out the logs as well and deliver them in the St. Mary's River, this location was found impracticable, as the creeks are all quite crooked and have very little fall, and the work required to straighten and clear them out so as to form a clear channel for the logs would have been very expensive. Furthermore, these creeks having so slight a fall for a long distance from their mouth, there would have been too feeble a current to carry the logs or prevent the deposit of sediment.

It was therefore considered advisable to locate the effluent canal on as true a grade from the swamp to the river as the nature of the ground would admit, and it was decided to locate it on the summit of the ridge or water shed between two of the nearly parallel creeks, and through this a grade was established of 5 feet per mile. Thence a grade of 33 feet per mile for $1\frac{1}{2}$ miles, and from that point to the river a grade of 12.2 feet per mile were secured. These grades would give a strong current computed by Hagen's formula, $V = 2.425\ R^{\frac{1}{2}}\ I^{\frac{1}{6}}$ (meters) of 10.77 feet per second for the steepest part, and 6.55 feet per second for the remainder to the river, which would allow of the delivery of 1 440 logs per hour in the St. Mary's.

The bottom of this swamp is found to consist of 5 to 7 feet of rich vegetable mould, somewhat peaty, and below this a stratum of sand and then clay. The dip of the swamp appears to be about 1 foot per mile, falling from the river toward the center.

Feed gates for regulating the discharge are provided at the mouth of the canal where it leaves the swamp. Hagen's formula for V has been tested very carefully on the Seine and Memel rivers, and found to be more nearly correct for such rivers than even Kutter's.

By constructing a flume 4 x 4 feet, $3\frac{1}{2}$ miles long, to the St. Mary's River, on trestles, at a cost of about $30 000, we have available a water power of over 6 500 horse-power, by means of which the logs can be sawn into lumber as fast as delivered by the canal. Of course, a much larger flume might be made, and the horse-power increased.

The Holpati Saw Grass is an impassable morass of 112 000 acres, elevated 22 feet above the tide-water in Indian River, a salt-water lagoon on the east coast of Florida. The soil consists of black, rich muck, about 14 to 18 feet deep. The drainage of this immense tract is now entirely by the St. John's River, but it is proposed to cut the effluent canal east into the San Sebastian River, which flows into the Indian River. The St. John's River flows over 240 miles in a direct line, and probably over 450 miles by the sinuosities of the course, to fall 22 feet to its outlet in the Atlantic. There is no elevated ridge of more than a few feet surrounding this morass, and the length of the effluent canal will be 18 miles. Just north of this morass and adjacent to it, is a large saw-grass lake of some 12 800 acres, whose drainage is into the St. John's River. This whole region is so flat that its reclamation would

make it necessary to provide for the drainage of 468 square miles of adjacent water shed, and when the water is lowered in the Holpati Saw Grass the large saw-grass lake would also drain into it. In fact, the whole upper part of the St. John's River and bordering swamps would have to reverse their flow for a distance of 80 miles, or at least down to Lake Poinsett.

It will, therefore, be necessary to enclose the whole immense tract with a dike 60 miles in length, or deepen and clear out the natural channel of the St. John's River for a long distance, and proportion our drainage canal to carry all the drainage of the water shed, or, in lieu of clearing out the river, dike off all of it immediately below our works by a dike not less than 20 miles long. These are the problems presented in this work. In the former case the dike must cross the mouths of three streams—Podgett's Branch, Podgett's Creek and Fort Dunn Creek, which are from 800 to 1 000 feet wide, but shallow—which now discharge into the Holpati Saw Grass. I have estimated the cost of this reclamation at $1 100 000, allowing 20 per cent. for contingencies.

The reclamation and drainage of the Sorasota Saw Grass, in this State, was completed in 1886, and has been reported by me in the Proceedings of the Southern Society of Civil Engineers. This work has proved very successful, and the land produces excellent crops. The cost was $6.30 per acre. Area drained, 500 acres; water shed, 3 500 acres; fall to outlet, 6.5 feet in 7 000 feet to tidewater on Sorasota Bay.

The drainage operations of the Disston Company in this State have proved very successful thus far in the upper portions, and large quantities of sugar, besides rice and other crops, are now being raised on some of their drained lands. They state that they have raised as much as thirty tons of cane per acre, equal to 6 210 pounds of sugar, twenty bushels of rice, worth $3 to $4.50 per bushel, and sixty to eighty bushels of corn.

Many years ago hundreds of acres of salt marsh in the town of Ipswich, Mass., my early home, were reclaimed from the sea by diking, with which work I was connected and thoroughly familiar. No engineer was employed, and the work was done by the farmers. Large areas were successfully reclaimed and the outlets provided with sluice gates of the flop pattern set in the dikes. The mistake was made, however, of not building the dikes strong enough and of suitable material. The marsh sods, cut from trenches just outside the dikes, were generally used. These sods are too light, as they float in water when only partially dry. The muskrats also proved deadly enemies to the dikes, burrowing into them and filling them full of holes. These dikes were about 10 to 12 feet wide on the top, with slopes of not more than 1 to 1, the same on both sides, and heights of from 6 to 15 feet. Complaint was also made of the flop gates becoming clogged by grass and driftwood, and in one case the gates were taken out, and a shutter gate, sliding up and down

in vertical grooves in the flume, and worked by hand, was substituted. This was tended for a time by a man specially hired for this duty, but, as was to be supposed, he neglected it at times, and the result was several tides of salt water flooding the land, which, of course, killed all the sweet water grasses and crops. This work was done about 1855 to 1860. The result was that the dikes gave way and the land was flooded with salt water, and has been allowed to relapse into its original condition. The salt water killed the sweet grasses and plants, and for a long time the marsh was in a far worse condition than before anything had been done. This result may prove a lesson in such cases, and emphasize the fact that such works should not be undertaken except under the supervision of a skilled engineer, and that the details must be carefully attended to and the gates effectually guarded from fouling and made perfectly automatic in their action.

I have been especially interested in that part of Mr. Starling's paper which treats of the "hoofden" or spur jetties, as I have had some experience in these works, having been in charge as United States Assistant Engineer under the late General Q. A. Gillmore, Major J. C. Post and Captain W. F. Russell, Corps of Engineers, United States Army, of the construction, extension and repair of the spur jetties built on Amelia Island for the protection of Fort Clinch, Fernandina, Fla.

These jetties are situated on the northwest point of the island at the narrowest part of the gorge of Cumberland Sound, where the width to Cumberland Island is 5 900 feet. This width is increasing. In 1843 the surveys show that the shore line at Fort Clinch was fully 100 feet further out. In 1882, I made a complete triangulation and topographical and hydrographical survey of Cumberland Sound, under the direction of the late General Gillmore, and found that the gorge had widened several hundred feet since the last coast survey had been made. There used to be a lighthouse on the southeast point of Cumberland Island, the site of which has been completely washed away.

These spur jetties are 3½ miles from the outer edge of the bar, and are exposed at high water to the full sweep of the sea from the northeast, but at low water they are partially protected by the long north jetty on the north shoals and by these extensive shoals themselves, which lie 1 mile north, or just across the sound. There is 24 to 30 feet of water 200 feet beyond the ends of the spurs, which deepens rapidly to 60 feet. The mean rise and fall of the tide here is 5.80 feet and the mean velocity of the ebb tide is 2.00 feet per second and of the flood 1.80 feet; and the greatest surface velocity on the edge of the channel opposite the jetties was found by Mr. Paret (M. Am. Soc. C. E.) to be 5.00 feet, and the bottom velocity at the same place 2.80 feet per second. These latter velocities, being taken in the concave bend, are somewhat greater than obtain at the jetties, which are located on the convex side.

The jetties, as built, extend along the shore here for 4 000 feet, the

fort being nearly in the center. The erosion of the bank has been so great here that the walls of the fort were endangered, and in 1881 these spurs or groins were built, and located about 570 feet apart and normal to the shore line, which gives them a radial projection, as the shore is here a convex curve of about 3 000 feet radius.

The jetties were constructed of log mats, 40 feet in width, the logs not less than 9 inches at the small end, and laid transversely to the axis of the jetty. The "mat" was simply a raft of pine logs, with binders spiked on 8 feet apart, with 20 to 24 inch spikes. Saw-mill slabs were spiked on the logs between the binders. They were covered with 1 foot of broken quarry rock, which was afterward increased to about 1½ feet. The rock was principally granite and gneiss brought out from the north in schooners. Only one course of these mats was laid, and they were about 3 feet in thickness, including the stone. They extend from high water to a few feet beyond low water, and the top has the same grade or slope as the beach, between high and low water. The cross-section is flat on top. Those near high-water line were built in place, and those near low water were built elsewhere and floated into position and sunk by throwing on rock.

They have withstood the sea well, and answer the purpose intended. At first only four, stopping at low water, were built, but it was found necessary to increase the number to seven and to extend them a few feet beyond low water. Since their completion, the erosion has practically ceased, and the beach remains normal. The sand piles up in the seaward angle, near the high-water mark, to the top of the jetties and the high-water line now extends about 100 feet further out than the original line on the east side of each jetty.

George W. Rafter, M. Am. Soc. C. E.—Several years ago I was in the City of Cairo, at a time when the Ohio River was at full flood, the water in the Mississippi also being high. There was some apprehension that the levees of that water-locked town were not equal to the emergency. The water in the river stood several feet above the general level of the business portion of the town, and at a number of places "sand boils" were throwing out considerable quantities of water. To add to the general feeling of discomfort, the drainage machinery refused to work just at the time of highest water, though luckily repairs were soon accomplished and the inflowing water easily kept at proper level. I noted with surprise the large amount of water a "sand boil" would throw out without sensibly enlarging the crater or materially increasing in volume. Such observations as I could make seemed to indicate that the outflowing stream was the result of the confluence of a considerable number of very small ones, rather than a single direct connection from the point of outflow to the river, as otherwise it appeared difficult to account for their maintaining a uniform section at the crater.

The portions of Mr. Starling's paper which treat of the methods of

administering public work in Holland are, perhaps, as useful as any to the working American engineer, in that they serve to enforce the proposition that good work is only secured by sound administrative methods. His remarks in reference to the regulations governing the excavation of borrow-pits and the dressing of slopes of the same by experienced slope dressers, is a good illustration.

The feature of the Dutch specifications of including a list of uniform rates at which extra work will be paid for, is one which could well be generally adopted in this country without injury to the interest of the parties for whom work is done. In railway construction extra work is usually of such a character that it can be classified under some item of the contract, and accordingly becomes, so far as final settlement of the account is concerned, practically contract work; but in national, state and municipal work (and especially in the latter), the most diverse practice prevails. In the bulk of new construction in cities, such as laying pavements, building sewers, extending water mains, etc., all the elements are known, and competition quickly reduces the profit to a narrow margin. The tendeney is, under these conditions, for the contractor to put as large a price on all extra work as the nature of the case will allow, and considering the unsatisfactory way in which municipal work is frequently prepared for letting, I am not prepared to say, absolutely, that municipal contractors are not, to some extent, justified in getting all they can.

In some cases, railway specifications in this country have called for the payment of a fixed percentage on the actual cost of all extra work, 10 per cent. being, so far as I am informed, the usual figure. Municipal extra work also is sometimes paid for in this way, though it is believed frequently at a somewhat greater rate than 10 per cent.

It may be of interest to note that the most complete account, in American engineering literature, of the drainage of the Haarlem Lake, is that contained in the chapter on drainage in Holland, in Colonel George E. Waring, Jr.'s, "Sewerage and Land Drainage." The history of the project from its inception, two hundred and fifty years ago, to its completion in 1858, is there given, together with many notes on the methods of executing the work which are not found in Mr. Starling's brief reference. The large pumping engines are also briefly described, and some illustrative sections given.

Mr. Starling's interesting statement, however, respecting the necessity for the construction of a subordinate levee, thereby forming a secondary polder inside the primary one, is a useful supplement to Colonel Waring's more extensive discussion of this phase of the subject, and may be considered as bringing our information in reference to the Haarlem Lake drainage down to date. One farther fact of some value in the present connection may, however, be noted, namely, the size of the pumping engines employed in this drainage. The original pumping stations were those mentioned by Mr. Starling at Spaarndam, Halfweg

and Gouda. According to data given in Wheeler's "Drainage of Fens and Low Lands," published in 1888, the actual horse-power of the original machines may be stated to average, at Spaarndam, 280; Halfweg, 125, and Gouda, 360. In 1880 an additional machine was erected at Katwijk of 570 actual horse-power. The lift at this station varies from 0 to 7 feet, and the entire plant, consisting of six drainage wheels, can handle 2 000 long tons of water per minute to a height of 4 feet or 1 200 long tons per minute to the extreme limit of the lift of 7 feet. The combined machinery at Katwijk is further stated by Mr. Wheeler as being the largest installment of drainage pumping machinery yet erected in either Holland or England. Mr. Wheeler also gives the details of the mechanical features of these four large drainage plants somewhat more completely than they are elsewhere described in the English or American literature on the subject, his chief source of information being "Stoombemaling Van Polders en Boezems," by A. Huet, C. E., The Hague, 1885.

The Canal Pumping Works in Chicago may also be mentioned. These are designed to assist the outflow from the south branch of the Chicago River into the Illinois and Michigan Canal, and have a total capacity per minute of lifting 60 000 cubic feet of water to the height of 8 feet. This work is accomplished by four sets of centrifugal pumps (two pumps to each set), placed in a dug well below the surface of the water to be lifted, and driven by a compound, vertical, condensing engine set between the two pumps and coupled direct. The actual horse-power required when all are working at full capacity to the extreme limit of the lift of 8 feet is 910. On this basis we may conclude that this drainage pumping plant is much larger than anything in either Holland or England.

In Egypt, however, much larger plants than the foregoing have been erected and are in successful operation, the largest being those for assisting, during low water, the supply to the irrigating canal for the west district of the Nile delta, and the water supply of Alexandria. For this purpose two plants have been provided, one at Atfeh and one at Katatbeh ; the latter, erected in 1882, consisting originally of ten Archimedean screw pumps, each 39 feet long and 10 feet in diameter, with cores 4 feet in diameter. The Archimedean screws being found unsatisfactory, seven of them were removed the following year, and five vertical action centrifugal pumps substituted. The mean lift is about 8½ feet, with a maximum of 10 feet, and the entire plant is capable of discharging 2 500 long tons of water per minute to this height, yielding, when so doing, an actual net horse-power of about 1 700. So far as I have been able to learn, this is the largest pumping plant in use anywhere.*

* Further detail with references to the several sources of information may be also found in Wheeler's "Drainage of Fens and Low Lands."

The recently published "Special Consular Report, Canals and Irrigation in Foreign Countries," contains brief references.

In conclusion, the brief references in Mr. Starling's paper to many of the cognate heads may be taken as indicative of the difficulty which the author has found in compressing all the detail within the limits of such monographic writing as is suitable for papers to be read before this Society.

Robert Cartwright, M. Am. Soc. C. E.—Major Sears has taken exception to the statement by Mr. Starling that pure clay is the thing for puddling. This Mr. Starling has evidently overlooked in his paper, because I am sure that he knows that pure clay does not make the best puddle. The best natural puddle we have is in hard-pan, and if any of you have worked in hard-pan, you will have noticed that a great deal of gravel is encountered in it; it is also pretty hard to work, while pure clay can be easily worked. My experience has led me to work about 3 to 1; that is, I take pure clay, cut it up, and to every three barrows of it dumped down an embankment, or anything of that kind, I dump down a barrow of gravel and sand.

I have built thirty-four gas holders, and to have a leaky tank is a serious matter in a gas-works. They are located in various sections of the United States and Canada, and that means a great many different kinds of soil. I would like to ask Mr. Herschel whether or not clay will saturate; he has said that it would dissolve down. In that case it must necessarily saturate—a fact which I deny. Certainly, the bottom of the great lakes, being clay, would have had ample time to saturate or absorb the water since the creation of them. The tunnels at Cleveland and Chicago have demonstrated that fact.

Clemens Herschel, M. Am. Soc. C. E.—This touches on a subject upon which I have some strong feelings and opinions. We have just heard that pure clay does not make a good puddle, and instead of it is recommended a mixture of clay and of some other material, say of gravel. Now I desire to go a step farther; I do not want any clay at all. What in the world anybody wants to cart clay on the field of operations for, as is so frequently done, is something I have never found out. I have been at work handling water for a considerable length of time now, and I have never had any use for clay. Pure gravel, just as it comes from the gravel pit, will make a water-tight stop, when used between planks or in any other position for which puddle is used, as far as my experience goes, better than clay, or a clay mixture, ever did. Now, perhaps the reason that others do not say the same thing is, because they have never tried it. At all events I give you that as the result of my experience.

I would like to have my position clearly understood. It is simply this—that anything that can be done with clay, can be better done with good gravel. Clay will melt away just like sugar or salt; gravel will not. Clay is a dirty, slippery, disagreeable and treacherous substance to have around the premises; gravel is not. I have seen clay imported from a great distance in order to be put in bags and used to make coffer-

dams, or something of that sort, water-tight, when three or four days afterward fifty per cent. of that stuff had disappeared. If, instead of getting that expensive clay, in the instance I have in mind, had gravel been put in those bags, it would have done the work better and at less cost. Now, I understand that the art of puddling is to deposit material in such way that every particle has been touched or permeated by water, and that water is used to make it settle down in a mass. Whether puddle be made of one thing or another, if it is handled in that way it constitutes puddle. I am a great deal like my friend, Mr. Worthen—I have not been brought up "that way"; we have got along pretty well without it, and don't want any clay, unless we are forced to build upon it.

In answer to Mr. Cartwright, I should say that "saturate" is hardly the word.

William E. Worthen, M. Am. Soc. C. E.—In my practice I have never had occasion to make use of a clay puddle ditch in an embankment; there has always been some binding material like clay, loam or hard-pan in the excavation which answered my purpose, and the bank was made of a uniform material for its full width, in layers of about 6 inches and compacted by the travel of the carts which came up on one side of the reservoir dumped its load where required, and returned to the same side, each cart making a complete travel around the top of the work. When necessary, the earth was sprinkled as deposited and occasionally rollers were employed.

When the reservoir made by damming a stream, or hillocks break the continuity of the bank, the weakness lies in the natural earth and its connection with the dam at the sides and bottom, and if the dam be made of the same kind of earth, it will retain water better than the earth which has not been moved, and will be stable if there is an embankment sufficient to sustain the load and wide enough to make the water which might percolate through traverse so long a distance that its flow is checked to a mere ooze.

Phineas Ball, C. E., constructed a dam at Clinton, Mass., with a concrete wall in the center, but nothing but sand and gravel at the sides and beneath. In such a construction I have found that the water from the reservoir percolates through the gravel and stands at a head very nearly equal to that of the reservoir, at the wall, and close to the wall and on the opposite the side the head falls off, diminishing toward the foot of the slope.

At Lowell, where it is necessary very often to put in sheet piling to cut off the water of the canals from the excavation for new construction, the canals are drawn off and sheet piling is usually set and slightly driven in trenches about 4 feet deep, which are filled with puddle on the canal side. This puddle consists of a glacier till from the disintegration of granite rocks, which is scattered in water of very little depth, merely enough to wet the till. The mass becomes compact very quickly,

and is always stanch, although it is subjected to the full head of the canal within a few hours.

ESTEVAN A. FUERTES, M. Am. Soc. C. E.—I have had a peculiarly fortunate experience in this matter. In about the year 1875 I built a system of water-works under the control of a literary corporation. I designed to pump something like 100 000 gallons per day into a reservoir, built on the French system; that is, without a puddle core or wall, which was in this case impossible on account of the fact that the site of the reservoir was a stratified clay and sand hill for an indefinite depth below the surface. Also there was not enough money for any other than the cheapest possible construction. The entire volume of the surrounding bank or enclosure was built from the material excavated from within the reservoir. Its banks have an internal slope of 2 to 1; a pleasure drive on the top, and sodded external slopes 1½ to 1. The specifications called for a surface puddle lining, of three volumes of brick clay (near by) and one volume of sand, laid 2 feet thick perpendicularly to the slope, or 4 feet horizontally. This puddle was to be paved with stones 10 inches deep, the joints in a vertical plane perpendicular to the top line of the bank, and grouted with Portland cement 2 to 1. The bottom of the reservoir had likewise a layer of puddle 2 feet thick covered by concrete 10 inches thick. This concrete was made up of one volume of Portland cement to three of sand, mixed dry, with five volumes of broken stone and enough water to need considerable and rapid pounding to make it sweat. The water supply was admitted, distributed and wasted through two 6-inch, one 8-inch and one 12-inch iron pipes cutting through the bank and terminating within a circular tower 9 feet in diameter. This tower was built at the toe of the inner slope, provided with gates, two separate chambers, an ornamental circular railing, and connected with the bank by a rustic bridge.

The committee controlling the works, though with the best intentions, harassed me not a little in the usual way; and when the reservoir was completed, in so far as form, puddling and paving, there was a breach on its north bank 37 feet deep, waiting for the pipes which should have been laid through the bank long before, at the time of its consolidation in layers of a small and uniform thickness. The pipes ordered by fast freight were at last found stranded on the Erie Canal at a great distance from the works, late in December, when grouting was deemed inadvisable. Now commenced the vicissitudes of the works, which if recited in detail could be made quite amusing and even of professional interest. The reservoir was filled with 1 000 000 gallons, and at once leaked at the center of water pressure on its south and tallest new bank. Despite my advice to let matters alone until the spring, the reservoir was patched up, by the advice of some Western practical man, whose professional dictum was always: "Plug her up, gentlemen, till she is tight." Thus the reservoir was riddled with holes in six successive fillings and an equal number of leakages.

Though at this time I desired much to give up this job, I did not feel warranted in doing so for many important reasons, although even a practical farmer succeeded in having an order given to line the reservoir with straw during the winter months, now well advanced. When the spring opened and the straw was removed, I found, as predicted, that innumerable rats had made their home in the straw, and the stone pitching was covered with a thick coating of slime produced by the filtering of rain through the rotten straw.

The leaks were stopped completely as follows: sand in small amounts was sifted into the crevices, over the whole surface of the pitching. This was done by four men in six hours. Then, beginning at the highest point, water was played upon the sand through a hose, the sprinkler gradually working downward, till the stones appeared clear of sand on their external surface and embedded in about 2 inches of wet sand. On the next day grouting was poured into the joints by beginning at the lowest point, upon a strip 3 feet wide, along the entire bottom of the slope. Then the next higher band, 3 feet wide, was also grouted; by this method insuring complete filling of the interstices left in any one course by the downward leakage of the grout of the next higher courses; and so on till the entire internal surface was grouted. Two days thereafter, Saturday and Sunday intervening, the grouting had set, water was let in, and the reservoir has neither leaked nor needed the expenditure of one cent for repairs to date.

I may also mention that a filter had been built within the reservoir, made up of various layers of stone and gravel and topped by sand. This material was enclosed in a huge box receiving at the top the water to be filtered, and delivering the filtered water through a pipe at the bottom into the west chamber of the tower, and thence to the distributing main. The sand employed was of such a nature that it immediately became clogged and no filtration was possible.

We have in this interesting case a compact example of a puddle that would not hold water, and a sand that would become water-tight; but it would be hazardous to generalize upon these facts without reference to the physical nature of the materials and the wide variety of mechanical conditions under which they may be used. To my mind, the McAlpine axiom just quoted, that "water abhors angles," explains fitly the advantages of clay with sand when its use is properly indicated by favorable conditions. It is a fact that cannot be denied that a thick layer of homogeneous plastic clay exposed to moderate water pressure is impermeable as long as it is confined and cannot crack. The softening of the clay surface in contact with water helps the impermeability, by preventing cracks though capillary action, without giving rise to what is technically called a leak. In the reservoir in question, the puddle was confined on one side by the earth upon which it rested; and on the other, by the weight of the stone pitching. If the pressure of the

water on the clay is great enough in comparison with its thickness and with the softness of its backing, the water pressure will punch a hole through the clay at some specially weak point. Under these conditions, the power of suspension of the water may become zero; but its transporting power will grow to be equal to that due to the head acting on the hole and punched through the clay. Erosion must take place. The leak becomes turbid or roily by the transported material carried off from the bank; and if left alone, the leak will continually grow. But if, when the leak starts, a pebble is placed in the hole, the area of delivery will be so greatly diminished and the resistance to the flow so largely increased, that the transporting power of the water may be reduced to zero and the power of suspension will again become correspondingly active; so that the slightest thread or smallest particle of clay will become clogged in the narrow orifice of delivery, which will evidently cease to be an area by contracting into a mere line, and finally into isolated points, easily closed by the feeble current into which suspended solid particles, each smaller than its predecessor, are drawn to cork the leak.

If these considerations are correct, and they seem to be, for clean gravel, or clean quartz sand, cannot oppose the passage of water on account of the inevitable presence of vacuities, no matter how compactly the material may be condensed, then the result recited to have been obtained with sand and gravel dams must have been secured by the adventitious circumstance of the presence—in the sand used—of a variety of small sizes of sand down to impalpable dust, which filled up and finally clogged up all the vacuities in the face of the dam exposed to leakage.

The question then seems to resolve itself to this: In the absence of actual experience with the sand or gravel of an unknown locality, is the engineer warranted in running the risk of leaks (which are generally serious in earth banks), when the use of clay can exchange the chances of failure for the certainties of success? It may be said that if the engineer has had any experience, he will not use improper gravel for this purpose; but I am inclined to think that only the engineer of limited experience or of great experience in a restricted area or locality will advance this argument. Although "dirty gravel" of all kinds may be found over extensive areas, embracing several of our States, there are, however, many places where only clean gravel or clean sand can be obtained, and the only way to make such material impermeable is to fill up its vacuities with material of varying sizes comminuted down to at least one size smaller than the size of the smallest particle of water likely to wend its way through the material of the bank. That such is the mechanical condition of tight banks may be also proved by the instance just mentioned in reference to the clogging of filters, which is a familiar experience. In these cases care is taken to regulate the de-

livery of the filters by suitable choice of the sizes of the material employed, placing the finely broken material on the water or loaded side of the filter, and the coarser material on the delivery side. These filters invariably get clogged by the process above mentioned, which renders impermeable the water side surface, and the usual remedy is either reversal of the current to dislodge leaves, fibers, and their cementing silt, or by removal of the silt-compacted coating. It is from the formation of this silt-compacted coating that immunity against leakage is obtained. The recommendation to throw gravel over a leaky area, omitting the clay is, I fear, successful only because of the sand, clay or loam almost always present in a large number of gravel products, which is there in spite of the injunction to keep it out. The coarse gravel stops the outward motion of the finer gravel; the latter prevents the running of the sand; and the vacuities of the sand are clogged by the loam, clay or silt, which prevent the escape of the water.

Charles B. Brush, Vice-President Am. Soc. C. E.—Mr. Starling's paper is, I think, one of the most valuable and interesting that has been presented to the Society. I am surprised at the suggestions of Mr. Herschel and of Mr. Worthen to the effect that clay is unnecessary at all times in assisting an embankment to hold water. While it is true that under certain conditions very excellent results are obtained with the use of gravel, still equally good results are obtained with a proper mixture of clay puddle. For instance, I do not think it would be wise where rock had been excavated in the bottom of a reservoir to attempt to seal that bottom with gravel. In such case a clay puddle would be preferable.

In the case of a subterranean water supply, water is generally obtained from strata composed of water-worn or rounded stones. In making examinations for a water supply, we are almost sure to find it in such strata. Water is also found in large quantities in sand strata. Probably the most remarkable case of a subterranean water supply from sand strata is found at Memphis. The water-bearing stratum there is about 700 feet thick, and is composed of white sand of various sizes. Most of this sand will pass through a screen of 2 500 meshes per square inch. Eight million gallons of water were actually drawn from this stratum in twenty-four hours.

Edward P. North, M. Am. Soc. C. E.—I think there might be some difference in the action of clays when exposed to water. I was employed on what is now a part of the West Shore Railroad in 1864–66.

On that road a bank some 60 feet high was thrown up from a wet clay cut. Shortly after it was built it commenced sliding, and in 1866 the base had gone fully 1 000 feet; the bank was still sliding in 1874, and, I believe, had not stopped in 1880. It is not clear what agitated this bank so that it would not set, and it is submitted that it must have been saturated with water.

Another smaller bank about 30 feet high was built with wet clay, and there was a pool of water on the upper side of it. When gravel ballast was put on this it bulged on the lower side about half way down from the top. Any additional gravel placed on the road-bed apparently drove semi-fluid clay out from that bulge until the pool was drained, though at that time gravel enough had been put on the road-bed to make a gravel core nearly to the original surface of the ground. None of the banks on that road which were built of dry clay gave any trouble.

J. Foster Crowell, M. Am. Soc. C. E.—I think my friend, Mr. North, has confused the question slightly as to the suitability of clay for puddle, by introducing another of its defects as a material for embankments. The kind of trouble that came from the clay in the railroad embankment he describes is not the same kind of trouble that has been under discussion. In the railroad embankment it is a question of gravity, and a wet clay bank that slumps under the weight of the track can sometimes be effectually cured by the use of sand or cinder (not slag) for ballast, which, being lighter, remains on the surface instead of sinking into and displacing the clay.

As to the relative value of clay and sand in an embankment to restrain water, a case in my own experience may be interesting. I was building a railroad across a corner of the Dismal Swamp, where it was desirable to avoid culverts wherever possible; to meet all the conditions, a water-tight embankment for the roadbed was essential. There being a good supply of fine clay near at hand, I used it in preference, but soon found that the bank was not water-tight and was rapidly and continually being dissolved away, so to speak, by the water, notwithstanding that there was seldom any current. There was fortunately a deposit of sea sand near by, and I put it on top and on the slopes, about 6 inches deep on the top and somewhat thicker at the toe of slope. The rains soon compacted the sand and drove it into the clay, forming with the water a practically impervious coating, and after that there was no trouble whatever. It was not, you will observe, the sand alone that did that; by itself the sand would have been too unstable even against the winds. I found, too, that clay and sand artificially mixed made excellent ballast for track, for which use neither alone was suitable.

So I think it is not exactly correct to condemn clay as a material *sui generis*. There are all kinds of clays, all kinds of gravel and all kinds of sand. As the artist said of his colors, they should be mixed "with brains."

John Bogart, M. Am. Soc. C. E.—It occurs to me that in this discussion the word "gravel" is used by some of our members as meaning quite a different material from the material which is spoken of as gravel by other members, and I think that this difference of meaning exists in different parts of the country. At many places the word gravel is un-

derstood to mean a mass of rounded stone of varying sizes. This sort of gravel occurs in very large deposits at many places and it is similar in the form of its constituent parts to the gravel of the seashore.

The other sort of gravel is made up of stone not rounded, but rather of flat shape, and with many particles of very small size, but still not rounded. It is with this latter sort of gravel that tight puddle can be made without the admixture of clay, and it is to this sort, doubtless, that reference is made in speaking of gravel used for puddle and without the admixture of other material. The method suggested by Mr. Worthen of determining whether a gravel will puddle would apply to this latter sort of material, but the gravel composed entirely of rounded pebbles of varying sizes will not make a tight bank alone, and in many places where clay occurs, and only this sort of gravel can be found, an excellent puddle is made by a suitable admixture of the two. This is the case in the banks of the canals of the State of New York at many points, in which a section of such puddled material is formed in the center of the bank, and which, when cut into afterward, is found to be compact and impervious.

W. R. Hutton, M. Am. Soc. C. E.—I find clay to be the very best material to make a water-tight embankment. I have not known it to crack—it has this disadvantage, that it is liable to be perforated by muskrats. A certain amount of clay is almost indispensable in making a water-tight bank, although a very small proportion in sandy or gravelly material will be sufficient, if well puddled.

Mendes Cohen, Pres. Am. Soc. C. E.—I have had some experience with just such slippy embankments as Mr. North has described, and have found the trouble due not so much to the material of the bank, as to the lack of proper preliminary drainage of the slopes on which it rested. As soon as this was effected the slipping ceased.

J. J. R. Croes, M. Am. Soc. C. E.—The relative merits of clay and gravel for restraining the passage of water through an embankment were discussed very fully by Mr. William J. McAlpine in a paper read by him in 1868, and published in Volume I, page 57, of the *Transactions* of the Am. Soc. C. E.

A favorite axiom of the author was thus enunciated in that paper: "Water abhors angles, and by compelling it to make a sufficient number, its head can be entirely destroyed, and prevent any damage." He continued: "Many young engineers fill their piling trenches with clay puddling, but the author greatly prefers fine gravel with a little loam mixed with it. The particles of clay are cohesive, and a vein of water ever so small which finds a passage under or through clay is continuously working a larger opening. The particles of fine gravel, on the other hand, have no cohesion. Such a vein of water as has been mentioned first washes out from the gravel the fine particles of sand, and the larger particles fall into the space, and these small stones first intercept the coarser sand and next the particles of loam which are driven in

by the current of water, and thus the whole mass puddles itself better than the engineer could do with his own hands. An embankment of gravel is comparatively safe, and becomes tighter every day; one of clay is much tighter at first, but is always liable to breakage from the causes already mentioned."

Mr. McAlpine stated that he presented this paper to show his practical experiences, such as the substitution of gravel for clay to resist the escape of water in dangerous places, and the method of preventing the passage of water along smooth surfaces by fatiguing it with angles. This latter principle he illustrated by his use of sheet piling placed by hand instead of being driven, and with battened joints.

The doctrine of Mr. McAlpine with reference to puddling is, I think, sustained by the experience of engineers, in the Eastern States at least.

By the term gravel is not meant a collection of clean, round, water washed pebbles of nearly uniform size, but a combination of small stones, sand and loam so proportioned that all the interstices between the stones will be thoroughly filled by finer material. In certain proportions clay is valuable in such a mass, provided that it is so situated that water cannot get at it so as to wash out the clay, which consists of very fine particles capable of being washed away by the action of running water.

A good illustration of the behavior of clay when used for puddling material in such proportions that its removal from the mass by water very seriously disintegrates the whole mass, occurred on the Ridgewood Reservoir of the Brooklyn Water-Works, built in 1857-60. The reservoir and embankment were built of material taken from the excavation and well rolled and rammed. This material was the Long Island drift. Where the reservoir was excavated below the natural surface of the ground, the banks were dressed to a slope of 1.5 to 1, and a puddle facing 18 inches thick at right angles to the slope was put on, consisting of clay and gravelly earth in about equal proportions. This material was wet, and cut with spades. Above the natural surface, the puddle wall was carried over the natural surface to the center of the embankment, and then carried up vertically in the center of the embankment. These banks were faced with a slope wall of split boulders about 12 inches thick, with the interstices well filled with pinners. When the reservoir was built, the water dissolved the clay out of the puddle and the slope wall slid in some cases and settled back in others, and it was necessary to empty the reservoir and relay the whole of the wall in cement mortar. Since that time I have never attempted to use clay in puddling to which water could find access, and I think in general the less of such material that there is used in puddling a wall, the better the wall is.

William Starling, M. Am. Soc. C. E.—I believe in maintaining the purity of the English language, and am altogether opposed to the intro-

duction of foreign words where there are equivalent expressions to be found in the vernacular tongue. Where these do not exist, it conduces to precision and brevity and avoids awkward circumlocutions to use the foreign term, having once explained its meaning. How will you render into pure English such words as gondola, kayack, howdah, samovar, diligence, boomerang? These words represent things which do not exist in England or America. Consequently, we have no names for them. You may, if you choose, call a gondola a barge, or a samovar a teakettle, or a howdah an elephant-saddle, but you will thereby convey an altogether imperfect and erroneous idea of the things alluded to. How shall we render the word *polder?* Shall we adopt the Indian plan, and call it a diked-field-which-has-been-pumped-out? and shall we use this paraphrase whenever we wish to speak of this thing? A *droogmakery* is something which has no existence outside of Holland, so far as I know, and there is therefore no equivalent for it in any other language. I suppose a *perkoenpaal* might be called an anchoring-stake, or a *zinkstuk* a mattress, or a *hoofd* a spur-dike, but those English expressions would convey only misleading ideas of the things themselves, which differ widely from the types of the same constructions which prevail among us. The outlandish words used are not more than half-a-dozen in number. The above list comprises nearly all of them. To learn that much Dutch cannot be a serious strain to a moderately robust intellect.

Metrical measures are used in the paper when the dimensions are derived from foreign sources—feet when given as the result of personal observation or estimation. It is to be presumed that every member of this Society is more or less acquainted with the metrical system. I have no special familiarity with it myself, but I am not puzzled when I am told that a bank is four or five meters high. I cannot think that is necessary, every time the word meter is used, to put after it, in parenthesis (3.28 feet). To render metrical dimensions which are given in round numbers into feet gives an appearance of spurious particularity. Suppose it is said that a berm should be 32.8 feet wide, the question immediately suggests itself, why this precise distance? But if the measure be given as 10 meters, we readily understand that no special exactitude is required.

The remarks on the use of clay as a material for dikes have led to a very interesting and instructive discussion. Some gentlemen seem to have interpreted them as a general declaration on the part of the Dutch engineers or myself in favor of the exclusive use of pure clay in water-tight bank of all kinds. It ought hardly to be necessary to say that this is a grave misconception, which could only have arisen from a very hasty reading of the paper, and a failure to understand the conditions of dike construction as they exist in the Netherlands and also in the Mississippi Valley. The remarks in question are a nearly literal translation of a passage in Storm-Buysing's "Manual," supported by the

evidence of engineers of the present day. It was thought best to give these opinions on their merits, without the expression of any individual views, as was plainly indicated by the statement that they had been "compiled" from Dutch authorities. In the matter of dike construction, at least, the Dutch engineers are the masters of the world, and their expressions are entitled to great weight, even when they differ from our own notions. In order that it may be seen whether I have caught the meaning of the author correctly, I give a literal rendering of the whole passage from which the words of the text were extracted:

"The earth of which the dike is to be composed must be such as to cohere readily with itself and with the soil beneath it. The more cohesion the soil has, the more it is to be preferred; for the more will its different parts unite and form a compact mass, which can oppose a resistance to the water, and thus furnish a tighter dike. Clay is thus the most suitable earth for dikes, and for the most part is to be found along our coasts, where dikes are to be built. It is to be procured, by preference, from the outer side, but when the foreshore is scanty or wanting, it must be taken from the land side. Sand has very little coherency, and does not afford a water-tight and strong dike (belooft geen waterdigten en sterken dijk). Peat and swamp soil have too little specific gravity, often less than water itself, and must thus, as well as sand, be rejected from the dike. Mould or arable land, though far inferior to clay, is still much better than peat or sand, packs closely, by reason of the smallness of its particles. and is especially suitable for dressing slopes that are to be sodded, as grass grows very well upon it. Clay cannot always be had in a pure state or in sufficient quantity, so that inferior earths must sometimes be mixed with it. But if the precaution be taken to work the best and purest clay on and near the outside, and the inferior sorts in the body of the dike, such sorts may be used without great danger. There are examples of dikes that consist of very sandy soil and have a covering of only one meter of clay on the outer slope, yet they furnish very satisfactory dams. It is easy to be seen, however, that such a dressing of clay must be treated with the utmost care, and the slightest injury to the outer slope must be immediately repaired, for if so much of the clay be removed that the water comes in contact with the sand or peat, very little confidence can be placed in such a dike."

It will be seen that these opinions are expressed in the most emphatic terms, and they are confirmed by the General Regulations * and by information obtained from individual engineers.†

* "The least cohesive and least clayey soils are worked into the inner slope and under the crown of the dike; the heaviest and most clayey soil in or next to the outer slope."—"Algemeene Voorschriften," page 6.

† "At nearly every point where dikes are necessary along our rivers, we find an abundance of clay, which is produced by the river itself, and is of a very heavy quality. Of this material the dike is constructed. If there is only sand to be got, the dike is made a great deal larger, and the outside is covered with a thickness of clay amounting to from 0.50 to 1.00 meter. * * * Puddle walls or diaphragms of any kind are never used. An invariable rule is *that the best soil must be worked on the outside of the dike.*"—Lieutenant Wenckebach, of the Dutch Engineers, MS. Communication, 1889.

As has already been intimated, these remarks are not to be understood as applying to water-tight banks in general—a subject which did not come within their scope at all. They are applicable only to dikes, and Dutch dikes at that, and must be understood with due regard to the limitations which govern that class of construction and the conditions which prevail in their own and similar localities. It seems that it is necessary to reiterate that the rules which are prescribed for the building of ordinary dams or reservoir walls are not necessarily or even usually applicable to the construction of dikes. How little I have succeeded in making this understood appears from the fact that my friend Mr. Cartwright supposes that I have advocated the use of pure clay as a puddle—an error which is the more difficult to understand as there has been no allusion to puddle in the whole paper—that method of construction being expressly excluded. It cannot be made too plain that dikes are necessarily very cheap constructions, comparatively low in height, and exposed to the action of water only for a limited time. They must be built of natural soils only, no mixture by artificial means being admissible. The choice of material is very narrow, being confined to such as can be obtained within the limits of an ordinary haul. All material must be put up dry—the levees being often half a mile or more from the river, and water being usually as scarce in the dry season as it is superabundant during the floods. As to gravel, it might as well be proposed to build a levee of diamonds. Neither in Holland nor in the Mississippi Valley is any gravel to be found in the alluvial region, except such as is brought in barges, hauled by rail, or mined at a depth of fifty feet or so beneath the surface. We are thus confined to clay, sand, and mixtures of the two in variable proportions. Often one class of soil predominates, but sometimes two or more are found together. In such a case, it is possible to keep the classes separate, though with some trouble, and in Holland, as we have seen, this is done, the clay being thrown upon the front or water slope, and the sand and loam constituting the body of the dike. In America we have not yet attained to these refinements.

Now, "clay" and "sand" are themselves very indefinite terms. I am a little surprised to see from some experienced engineers such hasty and sweeping declarations about clay that it is treacherous, slippery, that it melts away like sugar or salt. Surely, these gentlemen do not require to be reminded that there are innumerable earths embraced under the general head of "clay," possessing widely dissimilar qualities. The plastic clays of the Mississippi Valley do not in the least deserve these reproaches. On the contrary, they are justly regarded as the most valuable soil that we have for the construction of dikes—and I suppose, from what little I have seen and read of the clays of the delta of the Rhine that they are very similar to the Mississippi clays. The latter are bluish or blackish in color, tough and waxy in consistency,

and resist the action of water like hard soap. When dry, they break up into innumerable small fragments—whence they are called by the general name of "buckshot" soil. When wet, these fragments swell and unite into a compact mass. With clay, as much depends on the method of handling as upon the nature of the material. The Mississippi clay shows to the best advantage when massed together. Its tenacity and cohesive power then come into play; whereas, if the particles become separated from one another and intermixed with particles of other soils, they lose this distinctive and valuable quality, and may then become unstable and treacherous. Banks of clay are most to be depended on if put up with scrapers or wagons, especially wheeled scrapers, where it is closely compacted together. Under these circumstances it will not slip or "slump." When put up with wheelbarrows, it is very granular in texture, and while still green is apt to become pasty under the action of water, and consequently to slip, that is, on the land side, for I have never known it to slip on the water side. After settling a year or so, it becomes pretty well compacted, and seldom slides, even when wet. When well packed, a "buckshot" levee constitutes a firm and tough mass, almost impervious to water, resisting the wash of rain or waves admirably, and without any disposition to slip, even though standing at a pretty steep slope.

The power of resisting the action of water is, of course, an extremely valuable quality, and it certainly is one of the principal reasons for placing it on the outer side of the bank, as Mr. Sears supposes, though not the only reason, as the Dutch engineers have assured us. Its usefulness in this regard is shown by the fact that it constitutes the outer layer of the hoofden, and of the bank-protections of different kinds.

Clay has one principal defect. It does not stand well at grade, but settles for an indefinite time and very irregularly, so that "buckshot" levees have to be repaired occasionally. However, such levees are very strong and trustworthy. Leaks in them, when they occur, are not usually dangerous, for they hardly "cut" or enlarge at all. Water may run over such levees for hours without destructive effect. A dike of this material, if the subsoil is good, may be of comparatively small dimensions and yet be tight and safe.

Pure clay is rarely to be met with. The clays of the Mississippi Valley are described by experts as being "largely siliceous" in composition, and in Holland it is known that the clay of the forelands, or recent deposits outside the dikes (the *battures*, as they would be called in Louisiana) contains a considerable quantity of sand, for which reason it is preferred for dike-building to the stiff or "fat" clays of the old sea-bottom, which are harder to work and more liable to crack and split.

I myself read with some surprise the emphatic condemnation by the Dutch engineers of sand as a material for dikes, and their declaration

that it would not make a water-tight bank. I have had to build many sand levees, and have had very little trouble with them. I am inclined, therefore, to think that the words above alluded to are not to be taken too literally, but rather in the sense that a much greater quantity of this material must be employed to effect the desired purpose. Sand levees, when of sufficient size and thoroughly sodded, answer very well, always stand at grade, and often, though not always, appear to be perfectly dry upon the back slope. It is possible that some of the discrepancies of opinion and observation here, as elsewhere, may depend upon the looseness of our nomenclature. There is very little pure sand to be found in the alluvial soil of the Mississippi Valley. It is mostly mixed with sufficient soil to bind its particles together. The defect of a bank of this material is that even when sodded it will not long stand the cutting effect of waves or overfall. Should a breach occur, it widens with fearful rapidity.

The Dutch likewise have frequently been compelled to make use of sand for their dikes. In such cases, when the dikes are important, they have been made of enormous dimensions, and covered, as already stated, with a dressing of clay on the front slope. The great Petten-Hondsbosch and Westkapelle dikes, mentioned in the text, are examples of sand dikes.

To sum up the case: dikes can be built only of natural soils, such as are found on the spot without artificial mixture. Of these soils there are only two varieties, namely clay and sand, mixed in various proportions. Of these, clay, of the kind prevalent in the alluvial regions of Holland and the Mississippi Valley, is the heaviest, toughest, tightest. and least subject to erosion. It requires far less of it to answer the same purpose. Therefore, it is preferred. Sand, however, can be made to do, if used in sufficient quantity.

These remarks refer only to dikes, and have no application to elaborate works, designed to stand great heads, where expensive methods are admissible, and where other material, such as gravel, can be easily obtained.

In answer to Mr. De Courcey, I would say that so far as I know, no use has been made of the roots of the basket osier as a protection against erosion or sliding. We are not usually troubled much with the latter, and as to the former, our levees are generally too far back from the river to have a strong current against them. Where the velocity of the current is dangerous, we have sometimes used spur-dikes.

As regards the alignment to be given to the ends of spurs, I think no particular attention is paid to it. The spurs are made nearly of uniform length, and the line joining their ends is consequently about parallel to the bank. In "caving" reaches, the latter is usually concave in trace, and hence the line of spurs has the same conformation. This is contrary to the practice of the Dutch, as laid down in the text, which prescribes a convex plan.

In Holland, as in America, the questions of channel-improvement and preservation of the banks have been closely conjoined with that of protection against overflow. However, those problems are immeasurably more difficult in the case of the Mississippi than in those of the branches of the Rhine.

Mr. Richardson refers to the burrowing of various animals as forming a serious difficulty in the way of maintaining a system of levees, and thinks that this matter demands special notice. So far as Holland is concerned, I have never seen any mention of this trouble in any of their books or specifications. I asked one of the most accomplished of the Dutch engineers, Mr. Leemans whether they had any difficulty in this particular, and he answered, very little—that occasionally they were somewhat annoyed by moles. I think that lower Louisiana must be peculiarly infested with pests in the shape of boring animals, from what I have heard, in the strong clay soil of that region. In Mississippi, public opinion is a good deal divided as to the part played by these creatures in producing leaks in or under the levees. Holes often appear. spouting clear or milky water, and sometimes continue unchecked for years. As long as they "run clear water" and are not formidable in volume or number, they are not regarded as specially dangerous, and generally nothing is done except to keep a close watch on them. Should they enlarge, or the water become discolored, they are usually "hooped," as the term is, that is, surrounded by a low semicircular levee, connected with the main levee at both ends, on the land side. This contrivance is exactly on the same principle as the Dutch device described on page 571. The "hoop" is not generally brought up to the level of the external water, for then the pressure would simply be transferred to the "hoop," which would not be desirable—but it is built 2 feet or so below the external level, so as to diminish the head, lessen the flow through the hole and, hence, the tendency to erode, and yet not excite a disposition to break out again elsewhere in the weak underground. Popularly, the crayfish are held answerable for most of the holes that appear, but I do not think a case has been made out against them. I have had many hundreds of so-called "crayfish-holes" explored and dug out, and usually a decayed stump or root was found to be the prime cause of the mischief. Where levees have been built through timbered land, though the stumps may have been closely cut down or even grubbed out, yet the lateral roots cannot be extracted. These penetrate to great distances, perhaps entirely under the base of the levee. Eventually they decay and form conduits for the water. It is true that crayfish are often or usually found in them, but it is doubtful whether they have any agency in producing or enlarging them. These leaks are generally found in levees known to be of faulty construction, or insufficient in size, and most of them disappear when the levee is enlarged. There are various animals that burrow more or less in levees, and elsewhere, such

as field-mice, rats, etc. I am told that musk-rats are particularly troublesome in Louisiana. One bird even—the kingfisher—has been detected boring horizontal holes as much as 8 feet deep. It is thought, with much probability, that beaver have caused several breaks. These animals are becoming rarer and rarer. In Mississippi, I do not consider the danger from boring animals as serious when the levees are otherwise sound and strong.

The interesting question raised by Mr. Richardson as to the transmission of hydrostatic pressure through weak and porous soils under the dike, is worthy of careful consideration. It may be, as he says, that where crevasses have resulted apparently from this cause, cavities of large extent existed in or under the bank. This is certainly possible, though in my opinion not likely, at least in all cases, for many crevasses of this nature have occurred in new levees, where there has been no time for the formation of such voids. However this may be, the provision against such a possibility would be of the same nature as has been suggested for the other case, and the frequency of breaks from underground pressure of some kind demands such a provision.

Both Mr. Richardson and Mr. Hider seem to agree with the Dutch engineers in attributing small importance to a "muck ditch." I think they have the strength of the argument on their side. Nevertheless, it appears to me that in those cases where I have used large and well-constructed muck-ditches, they have cut off considerable leakage.

Mr. Hider's remarks on banquettes I think perfectly just. There is another point of view from which the employment of banquettes appears to be correct practice—and that is the altogether faulty cross-section of levees built on the ordinary model, as regards hydrostatic pressure. The standard section of the Mississippi levees has a crown of 8 feet and slopes of 3 to 1 on each side. Such a levee, with the water standing at its very top, shows a proportion of breadth of base to height of external water as follows:

At the water surface	8 to 0, or	∞ to 1.
1 foot below surface	14 to 1, or	14 to 1.
2 feet "	20 to 2, or	10 to 1.
3 " "	26 to 3, or	8.7 to 1.
4 " "	32 to 4, or	8 to 1.
8 " "	56 to 8, or	7 to 1.
12 " "	80 to 12, or	6.7 to 1.
20 " "	128 to 20, or	6.4 to 1.

It thus appears that the greater the depth of the water, the less the strength of the levee, the weakness being manifested at the most dangerous of all places—at the base. The greater the width of the crown, the more conspicuously does this defect show itself. Now, a banquette gives strength where it is most needed, and in an economical manner. For this

purpose and for most others, the shape shown in the newest Dutch constructions is the best, namely, with a cross-section of a long segment. In the case of the Mississippi levees, the banquette is intended to be used as a roadway ; hence, it must have a regular crown. It is usually given a slope of 5 to 1.

In practice, it has been found that standard levees of 8 feet high or less never break ; hence, the grade of the banquettes has been fixed at that distance below the crown. The Dutch usage is very similar.